OPHTHALMIC MYOLOGY,

A SYSTEMATIC TREATISE ON THE OCULAR MUSCLES,

BY

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SIXTY-ONE ILLUSTRATIVE CUTS AND SIX PLATES.

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PREFACE.

Art cannot succeed when principles are unknown or ignored. The mechanical or surgical art of readjusting the ocular muscles, when there is maladjustment or imbalance, should be based on the scientific principles underlying ocular rotations, else such art should not be practiced. These principles, as simple as they are enduring, are discussed in Chapter I. of this volume, and with sufficient clearness, the author hopes, to enable the reader to fully comprehend them. Without a clear understanding of these principles, it will be impossible to grasp the teaching of subsequent chapters; but in the light of the teaching of Chapter I., the remainder of the book may be easily understood.

Whenever it has been possible, in the interest of truth, the author has been glad to agree with writers who have preceded him; when forced to dissent from their teachings, he has done so cautiously and respectfully, invariably giving his reasons for so doing.

If the aim of the critic—and the author hopes that every reader will be a critical reader—who may review this volume, shall be the establishment of truth and the dethronement of error, he will not become an object of

terror to the author; for he himself has been laboring, through a period of fifteen years, for the accomplishment of the same end, as it relates to the ocular muscles. He believes that what he has taught in this book is true, and that practice based on what he has taught will be correct. He would not promulgate nor perpetuate error if he knew it; therefore the reviewer who, in his own way, points out what he may find to be erroneous is as much his friend as the one who may give emphasis to what he finds to be true.

In the body of the book the author has given due credit to every writer and thinker on the subjects discussed, whom he had an opportunity to consult, and it only remains for him to acknowledge here the helpfulness he has derived from their labors.

For the mechanical excellencies of the volume, the author, who is also the publisher, is indebted to the printing establishment whose inscription can be found on the title-page.

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OPHTHALMIC MYOLOGY.

CHAPTER I.

THE FUNDAMENTAL PRINCIPLES OF OCULAR MOTIONS.

THE supreme law of binocular single vision is the law of corresponding retinal points. Through the guiding sensation, resident in the retina, nine conjugate innervation centers in the brain control the twelve extrinsic ocular muscles, in obedience to this law. The law of corresponding retinal points, so well known and so universally accepted as true, hardly needs more than a mere mention in this treatise. In its simplest form it may be stated that the macula in the one eye must correspond, point for point, with the macula in the other eye; that the vertical meridian of the one eye must everywhere correspond with the vertical meridian of the other eye; that the same relationship must exist between the horizontal meridians of the two eyes; and that any retinal point in the one eye, bearing a certain relationship to the macula, the vertical and horizontal meridians of that

eye, must correspond with a point similarly related to the macula and these two meridians in the other eye. If the eyes are so directed that the two images of an object looked at shall fall on parts of the two retinas that do not correspond, double vision must result, unless prevented by mental suppression of one image; for there are but two means of preventing diplopia, a forced fusion of the two images or a mental suppression of one image. Unless artificial interference is interposed, the twelve well-adjusted extrinsic muscles of the two eyes will always so relate the two retinas as to prevent diplopia.

It is interesting to study the effect of the action of an individual muscle, or pair of muscles, and locate the axis of the resulting rotation; and it is practical to do so, although no one ocular muscle, or pair of muscles, acts by itself. Primarily, the student of ophthalmic myology wants to know what are the resultant actions of the associated ocular muscles. There are but two things with which the six muscles of each eye are concerned: the one is the visual axis, and the other is the vertical axis whose plane is the vertical antero-posterior plane of the eye, and, therefore, includes the vertical corneo-retinal meridian. The visual axis beginning at the fovea centralis, passes through the center of retinal curvature, thence out through the cornea at or near its center, and on into space. With this axis the four recti muscles are

alone concerned as to the final result of their action. The superior and inferior recti of the two eyes are required to keep the two visual axes always in the same plane, whether that plane be horizontal, elevated, depressed, or inclined to the one side or to the other. The internal and external recti must so control these axes in that common plane as to make them intersect at the point of fixation. The oblique muscles are required to so relate the vertical antero-posterior planes of the two eyes that the vertical axes which lie in these planes may be parallel with each other, and with the vertical plane of the head.*

Law Governing the Recti and the Obliques.

From the foregoing the logical conclusion must be that the following is the law governing all possible ocular rotations: *The recti muscles must control the visual axes, the superior and inferior recti keeping them always in the same plane, the internal and external recti making them intersect at the point of fixation. The obliques must keep the vertical axes parallel with each other and with the median vertical plane of the head.* In orthophoria this law is implicitly obeyed.

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*In uncorrected oblique astigmatism these axes are converged or diverged above, in obedience to the law of corresponding retinal points.

The Innervations.

To accomplish their work these muscles have nine conjugate innervations:

(1) The one to elevate both eyes.

(2) The one to depress both eyes.

(3) The one to converge both eyes.

(4) The one to move both eyes to the right.

(5) The one to move both eyes to the left.

(6) The one to keep the vertical axes from diverging above.

(7) The one to prevent their converging above. These (6 and 7) are called into action by the guiding sensation, when the point of view is primary or in either one of the four cardinal directions.

(8) The one to maintain the parallelism of the vertical axes and the median plane of the head when the point of view is obliquely up and to the right, or down and to the left; and

(9) The one to maintain the parallelism of the vertical axes of the eyes and the median plane of the head, when the point of view is obliquely up and to the left, or down and to the right.

The innervations one to five are for the recti, and the sixth, seventh, eighth, and ninth are for the obliques. Each of the conjugate innervation centers con-

trols two muscles, one for either eye. The first controls the two superior recti; the second, the two inferior recti; the third, the two interni; the fourth, the right externus and the left internus; the fifth, the left externus and the right internus; the sixth, the two superior obliques; the seventh, the two inferior obliques; the eighth, the right superior and the left inferior obliques; and the ninth, the left superior and the right inferior obliques. The cerebral centers for these innervations have not been located. These centers are so intimately related that their innervation impulses cause the normal muscles to act in perfect harmony. The first and second conjugate innervations, acting in harmony, PLANE the visual axes; the third, fourth, and fifth regulate the angle of convergence of these axes; while the sixth, seventh, eighth, and ninth maintain parallelism between the vertical axes and the meridian plane of the head.

The Law of Rotations.

A study of the axes of all possible rotations is most interesting. There is not one law governing rotations from the primary position to any secondary position and another law governing rotation from one secondary position to another secondary position; but all these rotations obey one law common to them all. As can be easily shown, this law is: *The axis of every possible rotation*

is in the movable equatorial plane, and is always fixed at right-angles to the plane through which the visual axis moves from the first to the second position.

To find the axis of any rotation, the rule given by Helmholtz needs no amending. At right-angles to the plane common to the first and second positions of the visual axis, construct two planes in one of which shall lie the visual axis in the first position and in the other the visual axis in the second position. The plane common to the visual axis in the two positions may be named *a*, the plane passing through the visual axis in the first position may be named *b*, and the plane through this axis in the second position may be named *c*. The line of intersection of planes *b* and *c* is the axis about which the eye has rotated in passing from the one position to the other. Planes *b* and *c* being everywhere at right-angles to plane *a*, their line of intersection must also be perpendicular to plane *a*. A fourth plane, *d*, may now be constructed through the line of intersection of planes *b* and *c*, at right-angles to either plane *b* or plane *c*, and necessarily at right-angles to plane *a*. This plane *d* is the equatorial plane of the eye. If the rotation has been from the primary position to any secondary position, or from any secondary position back to the primary position, the axis of rotation is in both the equatorial plane which has moved with the eye, and also in the Listing

plane, which, passing through the centers of rotation of the two eyes, is fixed vertically in the head and at right-angles to the visual axis only when it is in the primary position. This can be true of only one eye at a time, for it is impossible for both eyes to be in the primary position at the same time. The primary position of an eye is that in which the visual axis is in the fixed horizontal plane of the head and, at the same time, parallel with the median plane of the head. In a normal state of the ocular muscles the two visual axes can never both be parallel with the median plane of the head; hence, the two equatorial planes cannot coincide, at the same time, with Listing's plane. Strictly speaking, the axes of rotation for the two eyes can be in Listing's plane only when moving in the horizontal plane. In all other rotations (vertical and oblique) either one or both axes is out of the Listing plane; but both are always in the equatorial plane. In rotation from one secondary position to another secondary position the axis is in the equatorial plane, but not in the Listing plane. There can be, therefore, no good reason for perpetuating the Listing plane.

It is easy to see how Helmholtz might agree that every possible rotation, beginning with the primary position of the visual axis, must be about an axis in Listing's plane; for, as already shown, this is true; but not more

true than that the axis is also in the equatorial plane. It is hard to understand how Helmholtz, after giving us the beautiful and correct rule for finding the axis of every rotation, could conclude that the axes of rotations from secondary positions to secondary positions are all to be found in a plane bisecting the angle between the equatorial and Listing's planes. This bisecting plane can never be at right-angles to the plane common to the first and second positions of the visual axis, and therefore no line in such a plane can be the axis of any conjugate rotation.

Vertical and Horizontal Fixed Planes of the Head.

If the foregoing argument is correct, Listing's plane, from the point of view of containing the axes of rotations, is of no value, and certainly nothing can be said in its favor as a plane of reference. There are, however, two planes of reference of exceeding value. The one is the median plane of the head, a fixed vertical plane passing down between the hemispheres of the cerebrum, and on down practically midway between the orbits. The other is a fixed horizontal plane of the head which, it may be said, always passes through the optic chiasm. If the two orbits are ideal in construction and position, this horizontal plane would bisect the lines of origin of the

interni and externi of the two eyes, and, passing on, would cut the centers of rotation of both eyes. Extended backward, this plane would pass, approximately, between the cerebrum and the cerebellum, just as the fixed vertical plane passes between the two halves of the cerebrum.

Fig. 1 represents these two planes, also the two eyes in ideal orbits. The line *A-B* is the fixed vertical median

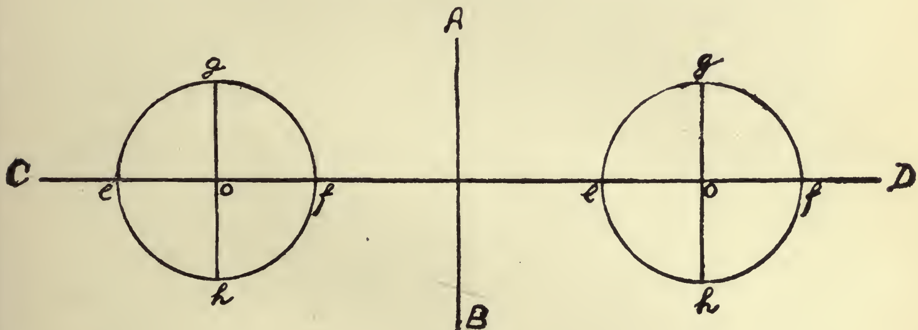

Fig. 1.

plane of the head; *C-D* is the fixed horizontal plane of the head; *g-h* and *g-h* are the vertical axes of the eyes, and *e-f* and *e-f* are the horizontal or transverse axes of the eyes. In orbits, whether well formed or malformed, the eyes must have their vertical axes, *g-h*, parallel with *A-B*. In well formed orbits, the eyes must have their transverse axes, *e-f* and *e-f*, lie wholly in the fixed horizontal plane of the head (*C-D*). This is true whether

the eyes are in the primary position or rotated in either one of the four cardinal directions or into any oblique position. Eyes contained in malformed orbits—malformed in the sense of being too low or too high—cannot have their transverse axes lie in the fixed horizontal plane of the head, but these axes must be parallel with this plane, whether above or below it, and that, too, regardless of the position occupied by the visual axes.

The parallelism of the vertical axes of the eyes with the median plane of the head, and the including of the transverse axes of the eyes within the horizontal plane of the head give us *correct* ideas of verticality, horizontality, and obliquity of lines in space, and that, too, regardless of the position of the head. A line that is seen vertical, when the head is in the primary position, will appear vertical still if the head be inclined 45° to the right or left, or to any other extent.

Disturb the parallelism of the vertical axis of the eye with the median plane of the head, by pressure made on the eye from below or above, so as to slightly tort the eye, and the line that was seen vertical will now be seen inclining in one direction or the other; the pressure ceasing, the eye at once rights itself and the line again becomes vertical. The same is shown, but to a greater degree, when there is a paresis or a paralysis of an oblique, or of a superior or inferior rectus (sometimes of an

internus or an externus) when, of necessity, the antagonizing muscles would tort the eye. Recovery from the paresis restores parallelism between the vertical axis of the eye and the median plane of the head, at which time objects will resume their proper positions in space.

If there is a paresis of an ocular muscle resulting in a torsioning of 10°, a line in space inclined 10°, so as to be parallel with the torted vertical axis, will appear to be vertical. The sound eye, whose projection has not been interfered with, on being uncovered, will see the line really inclined the 10°, and the patient will be thus made conscious of the false projection of the eye to which the paretic muscle belongs. This is proof that it is not the vertical corneo-retinal meridian, independent of its relationship to the vertical plane of the head, that determines true verticality.

The exacting task of properly regulating the vertical and transverse axes of the eyes to the two fixed planes of the head has been placed on the oblique muscles; and that, too, whether vision is binocular or monocular. This explains why the horse, although he is denied binocular single vision, nevertheless has oblique muscles.

When the head is *erect*, a line in space that lies in the extended median plane of the head, or is parallel with it, and is at right-angles to the extended horizontal plane, is *vertical*, and will be so seen by eyes whose ver-

tical axes are parallel with the median plane of the head. When the head is erect, a line that lies in the extended horizontal plane of the head, or is parallel with it and is at right-angles to the extended median plane of the head, is *horizontal*, and will be so seen by eyes whose transverse axes lie wholly within the fixed horizontal plane of the head. These lines will be seen vertical and horizontal not only when the head is erect, but they will be so seen with the head in any position whatsoever, for the reason that, in all positions of the head, the vertical axes of the eyes will remain parallel with the median plane of the head, and the transverse axes will continue to lie in the horizontal plane of the head; for, as these planes incline, the axes of the eyes incline also. A line in space, of any degree of obliquity, will be seen, by well-adjusted eyes, to bear its exact relationship to the vertical and the horizontal.

Our ideas of goniometry also depend on the same law. Since it is easier to determine that a line is exactly horizontal and that another line is vertical than it is to tell the exact degree of obliquity of a line, so is it easier to form an exact judgment of a right angle than it is of an oblique angle. For the same reason it is easier to form an exact idea of a rectangular figure than it is of any other figure unless it be a circle. If our judgment of the direction of lines and the degree of angles were a thing of acquisition,

and not a gift, then it might be true that our ideas of verticality and horizontality, obliquity and goniometry, would depend on a studied relationship of external objects. To prove that the conditions determining these ideas are within us and not without, and that these conditions are the fixed relationship (parallelism) of the vertical axes of the eyes to the median plane of the head, and that of the horizontal axes (lying in) with the fixed horizontal plane of the head, a device for the formation of a line in space, unassociated with any other line, is a necessity. The Stevens clinoscope is such an instrument, as is also the cyclo-phorometer. The latter instrument was tried on Mr. Hunter McDonald, Chief Engineer of the N., C. & St. L. Ry., among others, with the result that he readily detected a variation of 1° from both the vertical and horizontal; and missed the exact degree of obliquity, which was at one time 15°, at another 30°, and at another 45°, by only 3°, 4°, 0°, respectively. This was with one eye. With two eyes, the axis of one rod being vertical and that of the other horizontal, he readily pronounced the angle formed by the two lines a right angle, and detected a revolution of one rod through one arc of 1°.

Law of Corresponding Retinal Points.

If the position of a *line* in space is thus determined, any and every *point* on the line is located in its proper

place by the eyes whose vertical and transverse axes bear a proper relationship to the fixed vertical and horizontal planes of the head. Hence, it would appear that the law of corresponding retinal points depends on the predetermined relationship of the vertical and transverse axes of the eyes to the fixed median and transverse planes of the head.

That single vision with double images depends on the predetermined relationship of the vertical and transverse axes of the eyes to the median and horizontal planes of the head is easy of proof. Suppose the head erect, the two eyes looking at a line lying in the median plane, and bisected by the horizontal plane of the head. The extended vertical plane of the right eye has been rotated around the vertical axis to include the line in the median plane; likewise the vertical plane of the left eye has been rotated around the vertical axis until it intersects the median plane so as to contain the line looked at. The line now lies in three extended vertical planes, the median plane of the head, the vertical plane of the right eye, and the vertical plane of the left eye. In each eye the image of the line is on the vertical retinal meridian, half below and half above the transverse plane of the eye. In obedience to the law of projection the one eye sees the line located in space as the other eye sees it; that is, definitely related to the

median plane of the head, and there is but one object. Suppose another line looked at to lie in the horizontal plane, and that it is bisected by the median plane. Let the point of fixation be the point of bisection by the median plane. Not only does the median plane bisect this line, but the extended vertical plane of each eye bisects it also, at the same point. The image in each eye, of necessity, must coincide with the transverse plane of the eye, thus falling on the horizontal retinal meridian, half the image on one side of the vertical plane and half on the other side, both the image and the line throwing the image being bisected by the vertical plane of the eye. Each eye would see this line in space precisely where the other eye sees it, hence only *one* line, though *two* images. This would be true of both images, whether they extended one degree or many degrees, on the vertical and horizontal retinal meridians, respectively. What is true of the vertical and horizontal meridians of the two eyes must be true of every other meridian, so that meridian 45° in one eye must everywhere correspond with meridian 45° in the other eye, point for point, degree for degree, beginning with the macula. To see singly when there are two images, one in each eye, is a law of the mind, but it is based on the predetermined physical relationship (parallelism) that exists between the vertical axes of the two eyes and the median

plane of the head, and the including of the transverse axes within the horizontal plane of the head. The law of corresponding retinal points is unchangeable.

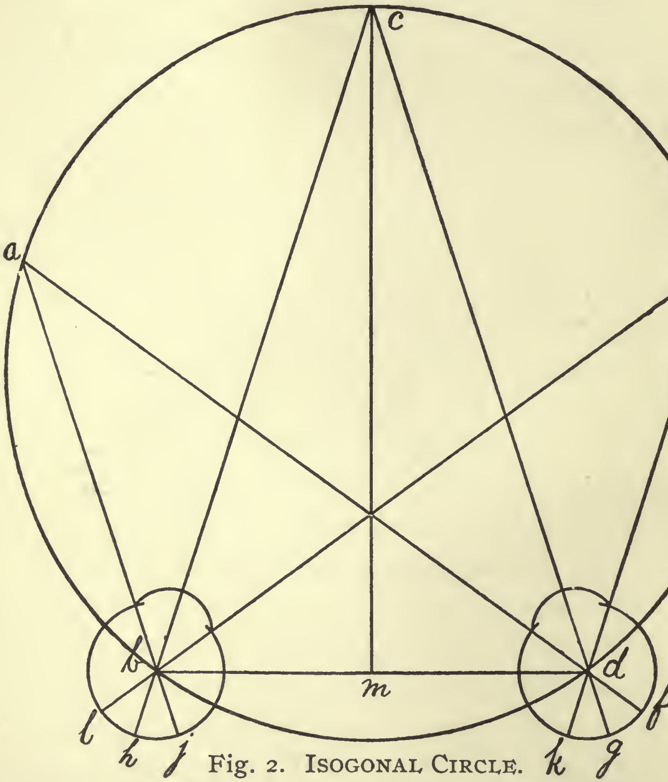

Fig. 2. Isogonal Circle.

Isogonal Circle.— The circle of binocular single vision for any given degree of convergence of the visual axes in the act of fixation, may be easily constructed.

By reference to the accompanying cut it will be seen that the three points chosen for the construction of the circle are: *c*, the point of fixation of the two eyes; *b*, the center of retinal curvature of the left eye; and *d*, the center of retinal curvature of the right eye. This circle of single seeing is in the plane of the visual axes. A point situated anywhere on this line, capable of sending rays of light into the two eyes, must be seen as *one* by the two eyes. The visual axis, *h-c*, and the visual axis, *g-c*, intersect at *c;* therefore the point *c* must be seen as one, an image falling on the macula of each eye. Point *a* on the circle sends rays of light (not shown in the cut) into both eyes. Those in the right eye strike the retina at *f;* those in the left eye, at *j*. The visual line *a-f* passes through the point *d*, and the visual line *a-j* passes through the point *b*. It can be proved that *j* is just as far on the nasal side of the yellow spot *h* as *f* is on the temporal side of the yellow spot *g*. Since the angle *a-b-c* is equal to the angle *h-b-j*, and the angle *a-d-c* is equal to the angle *g-d-f*, it only remains to prove that the angle *a-b-c* is equal to the angle *a-d-c*, in order that it may be shown that *j* and *f* are corresponding points of the two retinas. The angle *a-b-c* (an inscribed angle) is measured by half the arc *a-c;* the angle *a-d-c* (an inscribed angle) is measured by half the arc *a-c*. Since the two angles *a-b-c* and *a-d-c* are each measured by half the same

arc, *a-c*, the one must be equal to the other. In the same way it may be shown that the retinal points, *l* in the left eye and *k* in the right eye, are corresponding points.

If the visual axes were rotated so as to have their point of intersection at *a*, the angle formed by these axes in the new position would not be changed; for in each of the two positions the angle would be measured by half the arc *b-d*. If the point of fixation were *e*, the angle formed by the visual axes would still be measured by half the arc *b-d*, hence would be the same as when the point of fixation was *c*. The same would be true of any point on the circle that could be fixed. It is interesting to note that all angles formed by the intersection of visual lines at points on the circle would be equal, for they all would be measured by half the same arc, *b-d*.

Since two of the points (the centers of retinal curvature) through which the circle of binocular single seeing must pass, remain always the same, the size of the circle depends on the distance of the point of fixation. Whether the circle be large or small, points within it will be doubled, for the images cannot fall on corresponding retinal points, and points beyond the circle will be doubled for the same reason; and that, too, regardless of the point on the circle that may be fixed.

Not only is there a line of binocular single vision, but there is also a surface. This surface is generated by re-

volving the circular plane *a-b-d-e-c* on the chord *b-d*, which is also the line connecting the centers of the two eyes. Dr. Manning Brown, of Hopkinsville, Ky., a former pupil of the author, had a mechanic make one of these surfaces with a turning lathe. With the visual axes fixed on a point anywhere in this concave surface, every point in the surface would be seen as one.

The name of the circle of binocular single seeing which has become fixed in literature is *horopter*, the meaning of which is "the limit of seeing." *Monoscopter* would, it seems, be a better name, since its meaning is "single seeing." Both the line and the surface of single seeing with the two eyes may be called the *monoscopter*.

Neither *horopter* nor *monoscopter* is correct, strictly speaking. The line and the surface are certainly not the limits of vision, as *horopter* would imply. Nor is single seeing with the two eyes, as the word *monoscopter* implies, always confined to objects on the line or in the surface, unless such objects as are beyond and within are mere points, as will be shown further on. The name, *isogonal*, given this line by Maddox is far better, for everywhere on this line that the visual axes or any two visual lines might intersect, the angles formed would be equal. It is absolutely true that the angle formed by the intersection of any two lines that have come from the two retinas, through the centers of reti-

nal curvature, is equal to the angle formed by any other two lines similarly related, for each and every one is measured by half the same arc. In the strictest sense, the term used by Maddox is correct, and since there can be no objection to it, a fixed place should be given it in ocular nomenclature. The same name, with equal correctness, can be applied to the surface generated by revolving the plane of the circle on the chord connecting the centers of the two eyes. Maddox has truthfully said that angles formed by the two visual axes can be equal only when they lie in the same circular arc with the centers of motion of the two eyes. With equal exactness he might have said that any two visual lines intersecting in this curve would form the same angle. In saying so, Maddox unconsciously implies that "all lines of direction are radii of retinal curvature prolonged."

With the foregoing so undoubtedly correct, it will be expected that authors, including Maddox, will, in the future, have their figures representing the horopter remodeled. Maddox did not intend to convey the idea that his isogonal circle was the horopter. There are very few books now extant that do not show this circle passing through Helmholtz' nodal points and the point of fixation. The reconstructed figure should be called the *isogonal circle.* The isogonal surface is real, although it appears practically impossible to make a figure to represent it.

The objection already stated to the term *monoscopter* could not apply if only points in space should be considered; for points within the isogonal circle or surface, and points beyond, would all be doubled, while all points in the circle and in the surface would be single. This is not true as to objects large enough to throw images that subtend angles of a few degrees, or even a few minutes. If the diameter of the isogonal circle is 30 feet, practically nothing seen beyond that circle, even to infinity, is distinctly doubled, and nothing the size of an ordinary candle blaze, within the space between the isogonal circle with 30 feet diameter and another like circle with a diameter of 20 feet, is seen double. There is, of course, a spreading out laterally of the object, whether within or beyond this circle, for every *point* of the object is doubled in that direction. The projected image of the one eye so overlaps the projected image of the other as to make it appear as one. Let the diameter of the isogonal circle be only a few inches, then every object, whether within or beyond the circle, will be seen as two objects, because of the large angle of convergence. An angle of convergence larger than 34′ will result in a distinct doubling of the moon. An angle of 34′ is formed by the visual axes, the centers of the eyes being $2\frac{1}{2}$ inches apart, when the diameter of the isogonal circle is 20.2 feet. The image of the moon subtends an

angle of 34′, and for this reason a convergence of 34′ will double the moon, but the edges of the two will be touching. A smaller angle of convergence will cause the two projected images of the moon to overlap, the more overlapping the smaller the angle, and hence would appear as one transversely-elongated moon.

The reason for objects not doubling, even at infinity, when the diameter of the isogonal circle is 30 feet, can be well illustrated by an associated study of the angle of convergence and the size of the image of the moon. The angle formed by the visual axes in this circle is 22.8′. The image of the moon subtends an angle of 34′. Imagine a candle blaze at 30 feet, and the moon at 240,000 miles, both bisected by the extended median plane of the head. Now, imagine the plane of the vertical corneo-retinal meridian of the one eye intersecting the same plane of the other eye in the candle, which should be held a little below the visual lines passing from the eyes to the moon. The candle being bisected by the vertical planes of the two eyes has its images also bisected. To change the point of fixation from the candle to the moon, both of which are bisected by the extended median plane of the head, each visual axis must turn outward 11.4′ to become parallel, and practically they do become parallel when fixed on the center of the moon. The vertical planes of the two eyes intersect so as to bisect the disc

of the moon, whose images will likewise be bisected. Now, 17′ of the image of the moon is on one side of the vertical retinal meridian, and 17′ on the other side, at the macula. On again changing fixation from the moon to the candle at 30 feet, the plane of each vertical retinal meridian is carried outward 11.4′, the image of the moon not moving. When fixation was on the moon 17′ of the moon's image was on the outer side of the vertical meridian. Thus it is shown that when fixation is at 30 feet, the vertical meridian of the retina cuts the image of the moon 5.6′ from its outer margin. The same is true of the other eye. There are really the two moons, but projection makes them overlap each other about $\frac{1}{3}$, hence no distinct doubling. Even so small bodies as the planets appear to be, because of their great distance, do not appear double when the point of fixation is 30 feet distant from the eyes. This want of doubling is not confined to the neighborhood of the extended median plane of the head, but it extends to objects in all space visible to the two eyes; and for the reason that the intersection of visual lines at every point on the isogonal circle, where they can possibly do so, forms an angle of 22.8′, the same as the angle formed by the visual axes. This absence of doubling must greatly enhance the beauties of a landscape and of the starry heavens.

Another important feature growing out of the study of the isogonal circle is the easy determination of the angle of convergence, whatever may be the distance of the point of fixation. The mathematical formula for solving this problem is: *As the circumference of the isogonal circle is to 360°, so is the arc extending from the center of one eye to the center of the other, divided by 2, to the angle of convergence.*

The first member of this proportion is found by multiplying the length of the diameter of the circle, which is the distance of the point of fixation, by 3.1416. The third member of the proportion depends on the size of the circle and the distance between the centers of the two eyes. If the circle is large, the arc from the center of one eye to the center of the other is practically the same length as its chord, which is the straight line from the center of the one eye to the center of the other. If the diameter of the circle is in feet, then the arc must be expressed in a fraction of a foot, but if the one is expressed in inches, the other must be also. To illustrate: Let the diameter of the circle be 16 inches, and let the arc subtending the angle of the visual axes be $2\frac{1}{2}$ inches, then the following is the formula expressed in figures:

$$50.26 : 360° :: 2\tfrac{1}{2} \div 2 : X°.$$

From this it will be found that $X = 8.9°$. If the first and third members of the proportion were feet and a fraction

of a foot, and if the arc subtending the angle formed by the visual axes was always $2\frac{1}{2}$ inches, or $\frac{1}{5}$ of a foot, the work of determining the angle of convergence could be simplified as follows: Divide 36 (the result of multiplying 360 by $\frac{1}{5} \div 2$) by the product of the distance of the point of fixation (the diameter of the isogonal circle) and 3.1416. To illustrate: Fixation is at 1 foot. Multiply 1 by 3.1416 and the product is 3.1416; with this number divide 36 and the quotient will be 11.35°. For any given length of the diameter of the isogonal circle, the visual axes will form a greater angle if the eyes are wide apart than if they are close together. For comparison, let the diameter be 16 inches and the arc $2\frac{1}{2}$ inches; then the angle of convergence will be, as already shown, 8.9°; but let the arc be 2 inches, then the angle of convergence will be 7.16°, a difference of 1.74°. The following table is interesting and helpful, and is approximately correct. The point of fixation being 16 inches, the upper row of figures represents the pupillary distance and the lower row the angle of convergence of the visual axes for each:

2	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	3
7.16°	8.06°	8.5°	8.95°	9.4°	9.85°	10.3°	10.74°

As is well known, the metre-angle of Nagel is not formed by the intersection of the two visual axes, but it

is the angle formed by the intersection of one visual axis with the extended median plane of the head, the head in the primary position, the point of fixation being at a distance of one meter. Under these conditions, the angle formed by the visual axis of the other eye and the extended median plane of the head, is also a metre-angle; the one exactly equal to the other. The sum of the two angles constitutes the angle of convergence, so that the angle of convergence is two metre-angles of Nagel. Both the metre-angle and the angle of convergence vary with variations of the distance between the centres of the two eyes. The angle of convergence is a thing to be measured, but not more certainly than that the metre-angle is also a thing to be measured. The metre-angle, therefore, cannot be taken as a standard of measurement, because a standard must never vary. A yard must be 36 inches, whether one is buying or selling, and whether the thing bought or sold is cloth or tape. The very word *standard* means unvarying. The unvarying standard for measuring angles is the arc of a circle in degrees, minutes, and seconds. This standard, for reasons to be shown, should apply to the angle of convergence. If Nagel had taught that the metre-angle is the angle formed by the intersection of the visual axes at a distance of one metre, and had given to it twice the value in degrees that he did give it, there would be less objection to it. Even then, the me-

tre-angle would mean 3° 20′ with the distance from center to center of the two eyes 58mm; while it would mean 3° 40′ with the distance from center to center of the two eyes 64mm. After having determined the value of the metre-angle (the angle formed by the intersection of the visual axes of the eyes at the distance of one metre, the head invariably in the primary position) in any given case it would be very easy to translate any fraction of a metre-angle or any number of metre-angles into degrees. Distances less than a metre, therefore a fraction of a metre, would increase the metre-angle in inverse ratio; for distances greater than a metre, the metre-angle would decrease in inverse ratio. To illustrate: Fixation at $\frac{1}{2}$ a metre would give convergence of two metre-angles; $\frac{1}{8}$ metre would give a convergence of 8 metre-angles; but fixation at 2 metres would give convergence of $\frac{1}{2}$ metre-angle; fixation at 8 metres would give convergence of $\frac{1}{8}$ metre-angle. Let the value of the metre-angle be 3° 20′, then the above would be translated: 2 ma = 6° 40′, 8 ma = 26° 40′, $\frac{1}{2}$ ma = 1° 40′, $\frac{1}{8}$ ma = 25′.

The value of the metre-angle (the angle of convergence) for various distances between the eyes is given in the accompanying table:

Distance between the eyes in inches.	2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞	3
Value of one metre-angle.	2°54′38″	3°5′33″	3°16′28″	3°27′23″	3°38′18″	3°49′13″	4°0′8″	4°11′3″	4°21′58″

An interesting fact developed in working out the size of the metre-angle, is that for every $\frac{1}{8}$ of an inch increase of the distance between the eyes there is an increase of the angle to the extent of 10′ 55″. Knowing the size of the metre-angle when the base-line (distance between the centers of the eyes) is 2 inches, the size of the angle with the base-line $2\frac{5}{8}$ inches is found by adding to the former 54′ 35″, which is 5 times 10′ 55″. This would give $2° 54' 38'' + 54' 35'' = 3° 49' 13''$, just the size of the angle shown in the table, when the base-line is $2\frac{5}{8}$ inches.

To find the size of the angle of convergence in any given case, when the point of fixation is less than one metre distant, divide the size of the metre-angle in degrees by that part of a metre that measures the distance of the point of fixation, which, of course, means that you are to invert the terms of the divisor and multiply. To illustrate: Fixation at 16 inches is fixation at $\frac{1}{2.46}$ metre. Let the base-line be $2\frac{1}{2}$ inches and we have the following:

$$3° 38' 18'' \div \frac{1}{2.46} = 3° 38' 18'' \times \frac{2.46}{1} = 8° 57' 1''.$$

Again, let the point of fixation be 3 m, and the base-line be $2\frac{1}{2}$ inches. We now have

$$3° 38' 18'' \div 3 = 3° 38' 18'' \times \frac{1}{3} = 1° 12' 46'',$$

the size of the angle of convergence at 3 m. The base-line remaining the same, the angle of convergence at a distance less or greater than one metre, is to the angle of

convergence at one metre (the metre-angle), inversely, as the distance of the point of fixation is to one metre. The mathematical formula is that the tangent of half the angle of convergence varies inversely as the distance of the point of fixation from the middle of the line joining the centers of the eyes. But for small angles the above rule gives approximately the same results.

The reason for suggesting that the metre-angle be the angle formed by the intersection of the visual axes at one metre, and not the angle formed by the visual axis and the extended median plane, and that it be given a value double that given it by Nagel, is that the angle of convergence, or rather the nervous impulse from the third conjugate center, necessary to make this angle, is the chief factor in the formation of judgment as to distance. In fixing points to the right and left on the isogonal curve the angle formed by the intersection of the visual axis and the median plane of the head is confined to one eye, and is constantly changing in value, whereas the metre-angle, which is synonymous with the angle of convergence of the visual axes at one metre, remains the same everywhere when carried along the isogonal curve.

Law of Direction.

The law of direction is dependent on the predetermined parallelism of the vertical axis of the eye with the me-

dian plane of the head, and the including of the transverse plane of the eye within the horizontal plane of the head.

Lines of direction, in passing from the image of a line on the vertical meridian of the retina (the eye in the primary position), out into space, to corresponding points on the vertical line throwing the image, must cross the vertical axis of the eye somewhere. Do they cross in a haphazard, irregular way? or do they all cross this axis at its center, which is also the center of retinal curvature?

Likewise lines of direction, in passing from the image of a line on the horizontal meridian of the retina (the eye in the primary position), out into space, to corresponding points on the horizontal line throwing the image, must cross the transverse axis of the eye somewhere. Do they cross at varying points on this axis? or do they all cross at one point, the center of this axis, which is also the center of retinal curvature?

Conceive the eye to be in the primary position, so that the transverse plane of the eye coincides with the fixed horizontal plane of the head, and the vertical plane of the eye is parallel with the fixed median plane of the head. Now conceive a vertical line out in space, lying in the extended plane of the vertical corneo-retinal meridian and bisected by the extended plane of the horizontal corneo-retinal meridian. As the object (the line) is bisected

by the prolonged transverse plane of the eye, so is the image on the retina bisected by this plane; for the inverted image bears a mathematical ratio to the object. The central point of the image corresponds to the central point of the line, and these are connected by the visual axis. The upper end of the image corresponds to the lower end of the object, and these two are connected by a visual line which must cross the visual axis in the center of the retinal curve. Likewise the lower end of the image corresponds to the upper end of the object, and these two points are connected by a line of direction (visual line) that must also cross the visual axis at the center of the retinal curve. What is true of these two visual lines must be true of all other lines of direction. Therefore the law of direction must be: *Every line of direction is a radius of retinal curvature prolonged.* The rods and cones, the percipient elements of the retina, are so placed on the hexagonal cell layer of the retina that every one points to the center of retinal curvature. The lamented Le Conte graphically said: "The rods and cones see *ends on.*"

The vertical and transverse axes of the eyes, when properly related to the fixed median and horizontal planes of the head, determine accurately the direction of objects in space. Where these two determining axes cross each other all lines of direction must also cross.

The Individual Muscle and Its Plane of Rotation.

If the nine conjugate innervations were never defective, and if there were no such thing as heterophoria, there would be but little need for studying the ocular muscles as to their separate action or in the light of synergism and antagonism. In paralysis and paresis of an ocular muscle, a diagnosis can be made easily and quickly only when one knows what would be the result of unopposed action of the affected muscle.

The reader is supposed to be fully acquainted with the extrinsic ocular muscles, as to their origin, course, insertion, and nerve supply. With this knowledge already acquired it is easy to pass to the study of the result or results of the contraction of any single muscle. The axis of rotation of the eye by any one muscle must be at right-angles to the plane of rotation for this muscle. This plane must bisect the muscle at its origin and at its attachment, and must also pass through the center of rotation of the eye. As to the internus or externus, the relationship that the muscle plane bears to the horizontal plane of the eye indicates the exact rotation that will result from its action. If the rotation plane of the internus coincides with the horizontal plane of the eye, then this muscle will have only one result from its contraction; that is,

the eye will be turned directly in (adversion), the rotation taking place around the vertical axis of the eye. This action of the internus may be termed its *principal* action; and under such condition there can be no *subordinate* action of the muscle. Some may prefer the terms used by Dr. Maddox, viz., *pre-eminent* and *subsidiary* action.

If the plane of rotation of the internus does not coincide with the horizontal plane of the eye, the simple rotation is impossible. Let this muscle plane be inclined down and out, as it must be when the internus is attached too high, then the axis of rotation cannot be the vertical axis of the eye, for the former must bear the same relationship to the latter that the muscle plane bears to the horizontal plane of the eye. The unopposed action of this muscle cannot rotate the eye directly in, but associated with the adversion there will be superversion and inward torsion or declination, both of which are subordinate actions. Let the internus be attached too low on the globe, then its plane of rotation will have an inclination down and in, forming a definite angle with the horizontal plane of the eye. The axis of rotation will form the same angle with the vertical axis of the eye. Unopposed, the internus thus attached cannot rotate the eye directly inward, but, associated with the adversion (principal), there will be sub-version and an outward torsion

or declination. It is reasonable to suppose that the plane of rotation of the internus does not always coincide with the horizontal plane of the eye. Thus it is shown that, by error of attachment (too high or too low), an internus may be one factor in a hyperphoria or a cataphoria, and in a minus or a plus cyclophoria.

In like manner rotation by the external rectus muscle may be studied. If the plane bisecting the origin and insertion of this muscle, and passing through the center of rotation, coincides with the horizontal plane of the eye, its action will result in abversion (principal, without any kind of subordinate, action). If the muscle be attached too high, its plane of rotation must be inclined down and in, its axis of rotation making the same angle with the vertical axis that its plane makes with the horizontal plane. The action of the externus thus attached will have a triple result: (*a*) abversion (principal); (*b*) superversion (subordinate); and (*c*) an outward torsion or declination (subordinate).

If the externus be attached too low, its plane of rotation will be tilted down and out, forming a definite angle with the horizontal plane, and its axis of rotation will form an equal angle with the vertical axis. In contracting, the eye will be abverted (principal action); it will also be sub-verted, and there will be an inward torsion (subordinate actions). Thus it is shown that an externus

attached too high or too low will be one factor in the production of a hyperphoria or a cataphoria, and just as certainly a factor in the production of a plus or a minus cyclophoria.

It will be observed, from the foregoing, that either an internus or an externus attached in greater part above the horizontal plane, will have the superverting effect of a superior rectus; and that either muscle attached in greater part below the horizontal plane of the eye, will have the sub-verting effect of the inferior rectus. The torsioning effect of an internus attached too high will be in, while that of an externus with a too high attachment will be out. An internus attached too low will produce a plus cyclophoria, while an externus attached too low will cause a minus cyclophoria. Thus it will be seen that an internus will have the same kind of verting and torsioning effects as the superior or inferior rectus towards which its attachment is displaced. The external rectus will have the superverting or sub-verting effect of the superior or inferior rectus towards which its attachment is displaced, but the opposite torsioning effect. The practical nature of these observations will be shown in the study of operations on the lateral recti muscles.

The correctness of what has been said about the action of the internus or externus, when the plane of rotation does not coincide with the horizontal plane of the eye, can

be easily demonstrated by any one anxious to know for himself. To begin this investigation he must know how to construct the plane of rotation. *There are three points through which this plane must pass, viz.: the center of rotation of the eye, the center of the origin of the muscle, and the center of attachment of the muscle.* The first and second points are unalterably fixed; the third point may be in the horizontal plane, above it or below it. If the center of the attachment is above the horizontal plane, the position and inclination of the muscle plane is found by an imaginary rotation of the horizontal plane on *an axis which is the line extending from the center of the origin of the muscle to the center of rotation of the eye*, carrying it up to the center of the too high attachment. Rotation of the horizontal plane in the same direction and on its proper axis, finds the muscle plane for the externus, when it is attached too low. In the one case the inner part of the muscle plane is elevated, while the outer part is depressed; in the other, the outer part is depressed and the inner part is elevated. By an imaginary rotation of the horizontal plane on its fixed axis down to the center of attachment of a too low internus, there will be depression of the inner part of the plane and elevation of the outer part. In like manner the plane of rotation is found when the externus is attached too high. In either case the axis of rotation must be at right-

angles to the plane of rotation. A rubber ball and two knitting needles are necessary for the experiment. Three great circles should be marked around the ball: one, the equator; one, the vertical meridian; and the other, the horizontal meridian. One needle should be passed through the ball at the two points of intersection of the horizontal and the vertical meridians, to represent the visual axis of the eye. If the muscle plane coincides with the horizontal plane, the second needle should be passed through the two points of intersection of the vertical meridian and equator, to represent the vertical axis of the eye, which will be the axis of rotation for an externus or an internus correctly attached. If an internus is attached too high, its plane should be located, and the second needle should be passed through the ball so as to be at right-angles to this plane. The upper end of this needle would now penetrate the ball to the outer side of the vertical meridian, and posterior to the equator above; the lower end would penetrate the ball internal to the meridian and anterior to the equator below, and the same distance from these two lines as the point of penetration above. The course of the needle must be through the center of the ball (center of rotation) necessarily. Rotate the ball on the obliquely-placed needle as an axis and watch the first needle to determine the elevation of the visual axis, and watch the vertical meridian to see the character of the

torsioning. In the same manner the experiment can be made when an internus is attached too low; also when an externus is attached too high or too low.

The most remarkable feature brought out by this experiment is that the internus, when attached too high, causes an inward torsioning, while the externus, with a too high attachment, causes an outward torsioning, and *vice versa*, when the attachments are too low.

The origin, course, and insertion of the superior rectus, also of the inferior rectus, make it impossible for the plane of rotation for either one of these muscles to coincide with the vertical antero-posterior plane of the eye when in the primary position. The plane of rotation for either one of these muscles is made to pass through the center of the origin of the muscle, the center of rotation of the eye, and the center of the insertion of the muscle. It is only when either muscle has a very definite attachment that its plane of rotation can be vertical. A displacement in or out of the attachment of either the superior or the inferior rectus will not change the kind of rotation to be effected, but it would modify the extent of the three effects of its contraction. For simplicity of study, it may be considered, therefore, that there is a common plane of rotation for both the superior and the inferior recti, and that the plane is vertical, forming an angle of 27° with the vertical antero-

posterior plane of the eye. The axis of rotation must be at right-angles to the muscle plane, and consequently must form an angle of 27° with the transverse axis, but in the horizontal plane with it. The superior rectus unopposed has for its principal effect superversion, and for its subordinate results, adversion and an inward torsion or declination. The inferior rectus will have for its principal action sub-version, and for its secondary actions, adversion and outward torsion. Thus the superior rectus, while being the chief factor in a hyperphoria, may be also a secondary factor in the production of an esophoria, and of a minus cyclophoria. The inferior rectus, while the chief factor of a cataphoria, may also be a secondary factor both in esophoria and in a plus cyclophoria.

An oblique muscle, when unopposed, is incapable of a simple rotation. Its plane of rotation must be constructed in the same way as have been constructed the planes for the recti. In the case of the superior oblique, the point of origin through which the plane must pass is the pulley at the upper-inner angle of the orbit, and not at its real origin at the apex of the orbit. Since the inferior oblique arises beneath this pulley, and since the superior oblique may be supposed to pass directly above, while the inferior passes directly beneath, the center of motion of the eye, to be inserted directly opposite each other in the outer-posterior

quadrant, they may be said to have a common plane of rotation, which means, also, that they have a common axis, around which each must revolve the eye when unopposed by any other muscle. This plane is at an angle of 39° with the vertical transverse plane of the eye. The axis must be, therefore, at an angle of 39° with the visual axis. When the superior oblique contracts, its principal action is to tort the eye in, but always accompanying this are the subordinate actions, sub-version and abversion. When the inferior oblique is unopposed in action, its principal action is outward torsion, and its secondary effects are superversion and abversion. Thus it may be seen that the obliques may be a factor in three forms of heterophoria: (*a*) cyclophoria, (*b*) hyperphoria and cataphoria, (*c*) exophoria.

But the extrinsic ocular muscles do not act alone. In every act of binocular single vision, the triple task imposed on the twelve muscles, by the imperious law of corresponding retinal points, must be performed. The keeping of the visual axes in the same plane is the chief work of the superior and inferior recti, but they are aided in this work by the obliques, which are also sub-vertors and supervertors. The intersecting of the visual axes at the point of fixation is the chief, sometimes the only, work of the interni and externi; but the interni are helped by the superior and inferior recti, so that the point of intersec-

tion may not be beyond the object; while the obliques assist the externi to prevent the intersection from taking place between the observer and the object. The paralleling of the vertical axes of the eyes with the median plane of the head is the chief work of the obliques, but in doing this work they are hindered rather than helped by the recti. In sub-version, the superior obliques aid the inferior recti, but at the same time the former must counteract the mischievous outward torsioning effect of the latter. In superverting the eyes, the inferior obliques help the superior recti, but the former must oppose the inward torsioning effect of the latter.

The helping of one muscle by other muscles is synergism; the opposing of one muscle by other muscles is antagonism. Much help may be derived from the following

TABLE.

Internus	Synergists	Superior rectus. Inferior rectus.
	Antagonists	External rectus. Superior oblique. Inferior oblique.
Externus	Synergists	Superior oblique. Inferior oblique.
	Antagonists	Internus. Superior rectus. Inferior rectus.

Superior rectus in superversion	Synergists	Inferior oblique. A too high internus, or A too high externus.
	Antagonists	Inferior rectus. Superior oblique. A too low internus, or A too low externus.
Inferior rectus in subversion	Synergists	Superior oblique. A too low internus, or A too low externus.
	Antagonists	Superior rectus. Inferior oblique. A too high internus, or A too high externus.
Superior oblique	Synergists	Superior rectus. A too high internus, or A too low externus.
	Antagonists	Inferior oblique. Inferior rectus. A too low internus, or A too low externus.
Inferior oblique	Synergists	Inferior rectus. A too low internus, or A too high externus.
	Antagonists	Superior oblique. Superior rectus. A too high internus, or A too low externus.

It will be noticed that every ocular muscle has one more antagonistic muscle than synergistic.

The foregoing study of the individual ocular muscles will make the study of binocular rotations the easier. Rotation of the eyes in any one of the four cardinal directions cannot be hard to understand. Rotation to the right or left in the horizontal plane is effected by all

the twelve muscles under the stimulus of seven of the nine conjugate innervations, the sub-verting stimulus perfectly neutralizing the superverting stimulus, and the *in*torting stimulus just as completely neutralizing the *ex*torting stimulus. The axis of rotation is the vertical axis of the eye, and there can be neither elevation, depression, nor torsion while this rotation is being effected. It can hardly be claimed that the conjugate stimulus, which would move the eyes in the opposite direction, plays no part; for, if both eyes are to be rotated directly to the right, the internus of the right and the externus of the left must have a control current of nerve impulse sent to them, but a current much less powerful than is sent to the right externus and left internus. This is as necessary as that the conjugate innervation of the subvertors should be neutralized by the conjugate innervation of the supervertors. Thus it would seem clear that, in every rotation of the eyes, all twelve of the muscles are called into harmonious action under the influence of seven of the nine conjugate innervations, and all in obedience to the law of corresponding retinal points. With mathematical precision all ocular motions must be accomplished.

The rotation of the eyes directly up is in the vertical planes of the eyes, and the transverse diameters are the axes of rotation. In this rotation the conjugate inner-

vation for superversion is greater than the conjugate innervation for sub-version; the *in*torting stimulus, which is less, neutralizes the *ex*torting stimulus, which is greater, and the three conjugate innervations intended for the lateral recti hold them in perfect harmony. The same is true of rotation directly down, except that the conjugate innervation for sub-version is greater than that for superversion, and that the *in*torting stimulus is greater than the *ex*torting stimulus. That the obliques have something to do with movements directly up and down is evident from the fact that, in the upward movement, the superior recti being more powerfully stimulated than the inferior recti, there would be *in*torting of both eyes, if the inferior obliques did not counteract this. Besides this, the inferior obliques also help to supervert the eyes.

If in the simple rotation of the eyes all the muscles are called into action to fix the planes of rotation, it can hardly be denied that they all will be concerned in the more complicated rotations.

Changing the point of view from the primary position to any secondary position not in either of the four cardinal directions, can be accomplished in either one of two ways: Let the secondary point of view be 45° up and to the right. This may be reached by rotating the eyes directly to the right to a cardinal point immediately be-

neath the point sought, thence directly up to the point aimed at. The first of the double movements will be a rotation on the vertical axis; the second will be a rotation on the transverse axis. As already shown, these two revolutions will be accomplished without the slightest torsioning of the eyes, for no torsioning is possible in rotations around either the vertical or transverse axes. In the one rotation, the visual axes have been carried along the horizontal plane; in the other, along the vertical plane. In the other method of reaching the oblique secondary position, the visual axis of either eye is made to sweep along the plane common to its center of rotation, the primary point of view and the oblique secondary point of view, which will include the visual axis in the first and second positions. The axis of this rotation must be at right-angles to this plane, which has an inclination of 45°; therefore, the axis must be at an angle of 45° also, and of necessity it must be in the equatorial plane. If action of the right superior oblique and left inferior oblique, under the stimulus of the eighth conjugate innervation, does not accompany this rotation, the oblique position cannot be reached without a great outward torsioning of the right eye and an inward torsioning of the left eye. This torsioning must be prevented, if the eyes are to have the same position—vertical axes of the eyes still parallel with the median plane of the head and horizontal

axes still in the fixed horizontal plane—which they would have had if the same point of view had been reached by, first, a rotation directly out, and, secondly, a rotation directly up. This can be accomplished only through the eighth conjugate innervation, which is divided equally between the superior oblique of the right eye and the inferior oblique of the left, the action under this stimulus being just enough to neutralize the torsioning that otherwise would result. In going in this most oblique direction the torsioning, if not prevented, would be the maximum. If the angle formed by the visual axis in its first and second positions should be 45°, the outward torsion of the right and the inward torsion of the left eye would be 9° 44′. The experiment showing this can be easily accomplished by means of the rubber ball and the three knitting needles. On carrying this rotation through 90°, the meridian that was vertical in the beginning becomes inclined 45° at the end of the revolution. Rotation in a less oblique direction would be attended by a slighter torsioning, until it is reduced to zero on reaching the horizontal or vertical plane.

The accompanying cut, Fig. 3, was designed by Maddox for solving "false torsion." It is taken from his very interesting book on "The Ocular Muscles," published in 1898. The following is the solution in his own words :

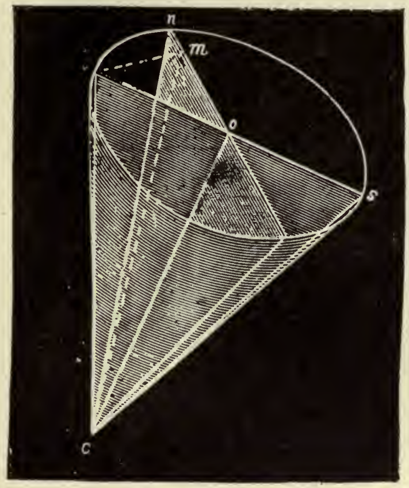

Fig. 3.

"Taking VC as unity—

Since $OV = \sin I$

and $\frac{OM}{OV} = \cos R,$

$\therefore \; OM = \sin I \cos R.$

Moreover $OC = \cos I;$

$\therefore \; \frac{OM}{OC} = \frac{\sin I \cos R}{\cos I} = \tan I \cos R.$

But $\frac{OM}{OC} = \tan (I - X);$

$\therefore \tan (I - X) = \tan I \cos R.$

Or $X = I - \tan^{-1} (\tan I \cos R)$

"Putting this into language: The false torsion is equal to the angle from the vertical, or from the hori-

zontal, of the axis about which the eye rotates, *less* the angle whose tangent is the multiple of the tangent of the inclination of the axis of motion with the cosine of the angle traversed by the line of fixation.

"The short table overleaf will give an idea of the amount of false torsion which takes place on looking in any diagonal direction midway between any two of the cardinal directions.

"Since the greatest false torsion of which the eye is capable occurs at the extremity of these diagonals, we may see at once that it does not ever much exceed 10°."

Rotation about an axis 45° from the horizontal.

Degrees	5°	10°	15°	20°	25°	30°	35°	40°	45°
Torsion	6½′	26′	1°	1° 47′	2° 49′	4° 6′	5° 40′	7° 33′	9° 44′

The above table was taken from Maddox.

At the author's request, Prof. John Daniel, of Vanderbilt University, designed Fig. 4, with the view of determining the amount of torsion that would occur as the result of oblique rotation of the eyes, if it were not prevented by the oblique muscles. The following is the solution by Professor Daniel:

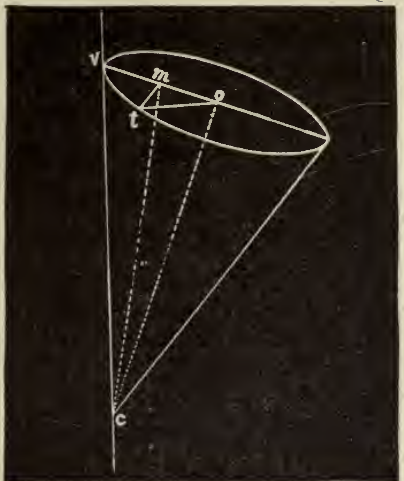

Fig. 4.

"Make $vo =$ unity.

$\mathrm{I} =$ angle between the vertical and the axis of rotation,

$= ocv.$

$\mathrm{R} =$ angle through which the eye is turned on said axis,

$= vot.$

Then $\mathrm{X} =$ angle of torsion, vcm.

$$\mathrm{X} = \sin^{-1}\left(\frac{\cos \mathrm{I} \operatorname{vers} \mathrm{R}}{\sqrt{\cos^2 \mathrm{R} + \cot^2 \mathrm{I}}}\right)$$ (for, in the triangle vcm, we have $\sin \mathrm{X} \div vm = \sin ovc \div mc$).

$$\sin \mathrm{X} = \sin ovc \frac{vm}{mc} = \sin (90^\circ - \mathrm{I}) \frac{vm}{mc}$$

$$= \frac{\cos \mathrm{I} \operatorname{vers} \mathrm{R}}{\sqrt{\overline{mc}^2 + \overline{oc}^2}} = \frac{\cos \mathrm{I} \operatorname{vers} \mathrm{R}}{\sqrt{\cos^2 \mathrm{R} + \cot^2 \mathrm{I}}}$$

$$\mathrm{X} = \sin^{-1}\left(\frac{\cos \mathrm{I} \operatorname{vers} \mathrm{R}}{\sqrt{\cos^2 \mathrm{R} + \cot^2 \mathrm{I}}}\right)$$

"That is, starting from a primary position, when the eye is rotated R degrees on axis inclined I degrees to the vertical (or horizontal) the resulting torsion, X, is an angle whose sine is equal to cos I times the vers R, divided by the square root of the sum of the squares of cos R and cos I. The numerical value of the torsion, X, when the inclination of the axis is 45°, is as follows for angles of rotation, R, as follows:

Angle of rotation = R = ...	5°	10°	15°	20°	25°	30°	35°	40°	45°
Torsion............	6½′	26′	1°	1°47′	2°49′	4°6′	5°40′	7°33′	9°44′

"This was worked out independently of the *simpler* formula given in Maddox, but the two are equivalent."

The mistake made by Maddox was in supposing that no effort was made by the obliques to correct the torsioning that otherwise would occur.

Other evidence than that given may be deduced to show that the torsioning threatened by rotations in oblique directions is not allowed to occur. An astigmatic, with his correcting cylinders (say of 2.00 or 3.00 D) placed in their proper positions and held as close to the eyes as possible, may be asked to look at an object up and to the right at the maximum obliquity. If torsioning has occurred, revolving the axes of the cylinders in

the direction taken by the best meridians ought to be necessary for the improvement of vision. In fact, any such revolution of the cylinders makes vision worse. Again, there are patients who have congenital marks on the eye-ball in or near the horizontal meridian, and there are others who have corneal scars, who may be made subjects of experimentation. If such a person should be asked to look up and to the right in the direction of maximum obliquity, the torsioning, if it takes place, should be easily detected. In fact, these marks, if in the horizontal meridian at the beginning, are still in the same horizontal plane at the end of rotation.

After all, the chief argument against the statement that torsioning actually occurs when the eyes are rotated in an oblique direction, is that, under such a condition, we would be wholly deprived of our power to judge of verticality and horizontality. If the obliques did not prevent the torsioning, the eyes, on looking up and to the right, or down and to the left 45°, would see a vertical line inclining to the left 9° 44′. An oblique rotation of the eyes does not deprive us of our idea of verticality. As already shown, our judgment of verticality depends on the fact that the vertical axes of the eye are parallel with the vertical plane of the head.

In oblique rotations up and to the right and down and to the left, the eighth conjugate innervation pre-

vents torsion by calling into action the right superior oblique and the left inferior oblique. In oblique rotations up and to the left or down and to the right, the ninth conjugate innervation prevents torsioning of the eyes by calling into action the left superior oblique and the right inferior oblique. Thus it is clear that the obliques have four conjugate innervations: the first, for both superior obliques, in cardinal sub-version, to prevent divergence of the vertical axes; the second, for the two inferior obliques, in cardinal superversion, to prevent convergence of the vertical axes; the third, for the superior oblique of the right eye and the inferior oblique of the left eye, when the rotations are up and to the right, or down and to the left, to keep the vertical axes parallel with each other and parallel with the median plane of the head; and the fourth, for the superior oblique of the left eye and the inferior oblique of the right, when the rotations are up and to the left or down and to the right, not only to keep the vertical axes parallel with each other, but also parallel with the median plane of the head.

If what is taught in the foregoing paragraph be true, then it follows that Listing's law must be false. While most readers may be familiar with the wording of this law, it is, nevertheless, reproduced here: "*When the line of fixation passes from its primary to any other position, the angle of torsion of the eye in this second position*

is the same as if the eye had arrived at this second position by turning about a fixed axis, perpendicular to the first and second positions of the line of fixation." Certainly it is around such an axis that the eye rotates from the primary point of view to the obliquely-placed secondary point of view. It is equally certain that there would be a torsioning unless a preventive force were called into action. If the obliquity of the plane of rotation be at the maximum (45°), and the rotation 45° in that plane, the torsion effected by the rotation from the one point to the other, as already shown, would be 9° 44′. Since no such great torsioning takes place, even when determined by after-images, it would appear that some effort is made by the eye to prevent it, at least in part; and if in part, why not wholly? The chief evidence in favor of Listing's law is the study of the after-image. After looking intently at a bright vertical line, with the eyes in the primary position, there can be no doubt but that the after-image will incline when the closed eyes are quickly rotated up and to the right; but no one has ever claimed that the leaning was so much as it would have to be if there were no effort at all made for the preventing of the torsioning of the eyes. The leaning of the after-image would be expected, for the stimulus of the after-image is not great enough to call into full action the eighth conjugate innervation, and without this, the vertical axes

cannot remain parallel with the median plane of the head, although they may be—must be if there is orthophoria of the obliques—parallel with each other.

The idea of uncounteracted torsion would have no place if Listing's law had been framed as follows: "When the line of fixation passes from its primary to any other position, the angle of torsion of the eye in this second position is the same *as if the eye had arrived at this second position by turning*" *first about the vertical axis, and then about the horizontal axis.* This would mean, of course, that the eye in its second position would have its vertical axis still vertical and its horizontal axis still horizontal.

CHAPTER II.

ORTHOPHORIA.

The terminology introduced by Stevens for indicating the relationship, normal and abnormal, between the ocular muscles, being of pure derivation, leaves no room for change and but little room for addition. These terms are so widely used and are now so well known, they need mentioning only when used in connection with the conditions indicated by them. The Stevens nomenclature was adopted as both scientific and correct, by the section of Ophthalmology of the American Medical Association, at the Washington meeting in 1891.

Orthophoria is the term applied to a perfect balance of the ocular muscles when the head is in the primary position and the eyes are looking straight forward. This condition, in the strictest sense, includes the idea that the twelve extrinsic muscles have all been perfectly developed, that each has its correct origin, pursues its proper course through the orbit to the eye, and is rightly attached to the globe; and that the orbits themselves are perfectly formed. It also includes the idea that the nine conjugate innervations are wanting in nothing. When

such a state of things exists, the visual axes are easily kept in the same plane through the first and second conjugate innervations; are always perfectly converged through the third conjugate innervation; and by means of the first, second, fourth, and fifth conjugate innervations, are made to sweep harmoniously along the horizontal plane, in the vertical plane, and in any oblique direction. Nor will the sixth, seventh, eighth, and ninth conjugate innervations fail to keep the vertical axes of the eyes parallel with each other and with the median plane of the head, and the transverse axes lying in the horizontal plane of the head, regardless of the location of the point of fixation. Such a condition would also include the idea that the verting and ducting power of all of these muscles is up to the standard. But for these eyes, thus well balanced, to be perfect, there must be no error of refraction. There are such eyes, and the happy possessor of them knows of their existence only for the joy they give him. The workings of such eyes never add anything to the sum of human ills.

There are accurate instruments for determining the existence of orthophoria. The Stevens phorometer, the only one in use for a few years, is represented in Figs. 5 and 6. This instrument being incapable of making all the tests, even for orthophoria, it was natural that others should be invented, and that the evolution would go on to final

perfection. The Stevens instrument is capable only of showing the state of balance between the different pairs of muscles, and in that much can determine the existence of orthophoria but not the kind, for; after all that has been said, there are two kinds of orthophoria. It cannot acquaint the operator with the duction power of a single muscle. It cannot, nor can any other phorometer, already known or hereafter to be invented, give information about the verting power. One serious objection to the Stevens phorometer, which applies with equal force to the Wilson phorometer next to be considered, is that it is a binocular instrument, and to that extent must be faulty. In all phorometers, either diplopia must be produced by prismatic action, the images in the two eyes being on non-corresponding points of the retinas, or the image in one eye must be made very different from the image in the other, as by the Maddox rod, so as to deprive the guiding sensation of the reins of control. In the Stevens phorometer both images are displaced so that neither eye can be in the primary position while under test. Again, if the patient be not orthophoric, rotation of the instrument to properly relate the two images, moves the image in each eye, which must be a source of inaccuracy.

The method of using the Stevens phorometer is simple. A candle or gas jet is placed twenty feet from the pa-

tient, who, in the sitting posture, should hold his head erect. Placing the instrument before him, he looks at the light through the prisms, when diplopia must become

Fig. 5.

manifest. In testing for lateral orthophoria the lights are made to appear the one above the other, by rotating the instrument so that the base of one prism may be di-

rectly up and the base of the other down. In orthophoria a vertical imaginary line will connect the two lights. If the one is not directly above the other, there is not lateral orthophoria. The slightest movement of these prisms will change the relationship of the images, and in this way whatever error may exist is measured.

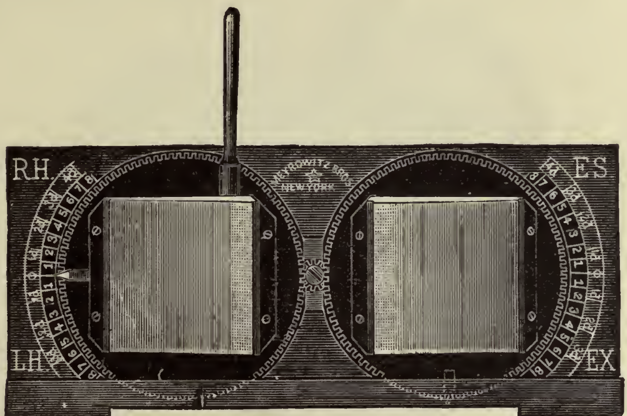

Fig. 6.

In the test for vertical orthophoria, the instrument is so rotated as to place the prisms with bases directly in. The two lights should now be the same height, but if not, then there is not vertical orthophoria. The rotation necessary to make the lights level shows the kind and quantity of the error.

This instrument can also determine the existence of oblique orthophoria. It must be rotated into the posi-

tion for testing for lateral orthophoria; but, for the light, a horizontal line must be substituted. The line will be doubled by the prisms and they should be parallel with each other.

The test of the lateral muscles and of the obliques should be resorted to in the near also. For the former,

Fig. 7.

a card with a dot or cross in its center must be held at the reading distance; for the latter, a card with a horizontal line on it should be held in the same manner. The dots and the lines should bear the same relationship as in the distant test. These tests made, the Stevens phorometer can do no more.

The Wilson phorometer, Fig. 7, can do all that the Stevens phorometer is capable of doing; and, besides, can determine the duction power of all the recti. The diplopia with this instrument is produced by a prism of 10° (found in one of the openings in the revolving disc) before the right eye, whose base can be placed up for a test of the lateral muscles, or in, for a test of the vertically-acting muscles. In lateral orthophoria the two images will be in a vertical line, when the slightest turning of the rotary prism constituting that part of the instrument which is always before the left eye, will displace the upper (true) image either to the right or left. Should the lower image not be in a vertical line with the upper, moving the rotary prism until the one is directly above the other will show both the kind and the quantity of the error. Changing the position of the disc, the 10° prism will present its base towards the nose. When the images are found in the same horizontal plane there is vertical orthophoria, and the slightest movement of the rotary prism will elevate or depress the one seen by the left eye. Should the false image be higher or lower than the true, moving the rotary prism in the proper direction will bring the true image into the horizontal plane with the false, thus showing both the kind and quantity of the vertical error. Thus far the workings of these two instruments practically correspond, the one being no bet-

ter than the other. With the Stevens instrument both images are moved in every rotation; with the Wilson instrument only the true image is made to change position. In connection with each of these phorometers there is the indispensable spirit level.

With the open space of the disc before the right eye and the rotary prism in a neutral state before the left eye, the prism axes being horizontal, by moving the rotary prism, the duction power of the superior and inferior recti can be taken, which should be 3°—certainly not less than 2°—for each. Since this revolving prism can measure 10°, it can always show, practically, the duction power of the vertically-acting muscles. Turning the rotary prism again into a neutral state, so the axis may be vertical, still keeping the open space before the other eye, abduction can be taken, which, in orthophoria, should be 8°—certainly not less than 6°. Rotating it in the other direction, adduction can be taken only up to 10°, its maximum power. To go higher than this, the disc before the right eye must be revolved until the 15° prism is brought into position, base out. Now, starting the rotary prism in the adduction arc, every movement adds to the 15° adduction caused by the prism before the right eye, until, when the end of the arc has been reached, 25° of adduction is shown. The doubling just now occurring, the conclusion is that adduction is normal; if soon-

er, that it is below normal. It cannot be carried higher by this instrument. It will be noticed that the test has been applied not to one internus, but to both, and for this reason cannot be reliable.

The Wilson phorometer is also capable of testing the balance and imbalance of the oblique muscles. To do this, the open space in the disc is placed before the right eye, while the rotary prism is before the left in the neutral position, axis horizontal. By revolving the prism as if testing for superduction, the point is finally reached when the horizontal line, which is now the test object, becomes double. If these two lines are parallel, then for that direction at least, there is orthophoria of the obliques. Returning to the neutral position, the prism should next be revolved in the direction of sub-duction. Presently the line is again doubled, the false line being below the true. If these lines are parallel, again there is evidence of orthophoria of the obliques. Not infrequently the false line in the latter position will show an insufficiency of the superior obliques, while in the former position the lines may be parallel. By slowly revolving the prism back towards the neutral point, whether from the one direction or the other, the patient can observe whether or not the fusion of the two lines is simultaneous throughout, or whether the fusion takes place at one end and then gradually throughout. When the lines are

not parallel, the kind of dipping indicates the character of error. This instrument is wholly incapable of testing the lifting power of the obliques.

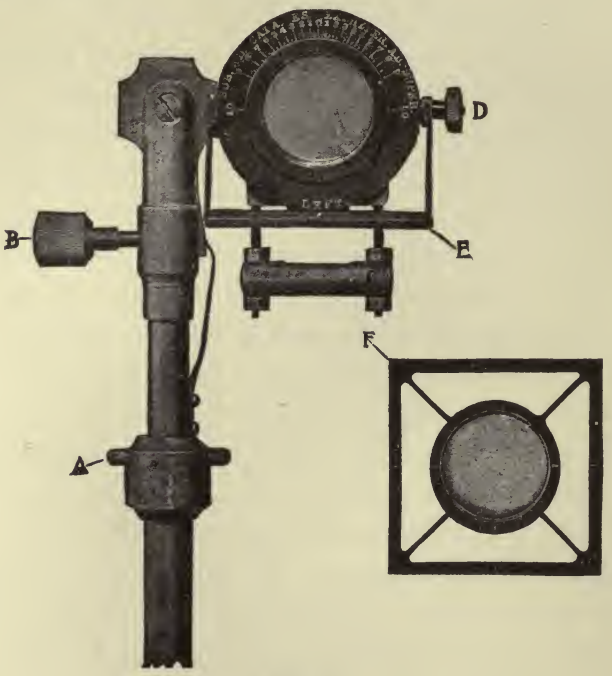

Fig. 8.

Neither one of these instruments is constructed on the correct principle underlying the tests of the ocular muscles, even when orthophoria exists. The principle on which all the tests possible to a phorometer rest, is that the image in one eye, throughout every test, shall be un-

disturbed; that the head shall be erect; and that both eyes and the object—better a white dot on a black background—shall be on the extended horizontal plane of the head. The false object must have its image thrown outside the area of binocular fusion in the eye under test, while the true object will have its image on the macula of the eye not under test, thus making it not only possible, but necessary, that this eye shall be in the primary position throughout the test, for it is not to have its image disturbed during any one of the several tests. An instrument based on the principle enunciated above is the monocular phorometer. It fulfills every essential condition, and is wholly reliable, and, except in rare cases, is invariable. The accompanying cut, Fig. 8, represents its appearance, but not its capabilities. The screw-and-spring arrangement, for regulating the spirit level, is as good as the best. In the base of the instrument there are slots on either side of the rotary prism, in one of which, towards the patient's face, is to be placed the displacing prism for causing the diplopia. If the instrument has been leveled, this prism, when placed in the slot, must have its axis either vertical or horizontal, and must produce a corresponding diplopia. The rotary prism differs from the one in the Wilson phorometer in that it has a face correctly lettered and marked in degrees, for each eye, and is easily reversible.

With the instrument properly leveled before the right eye, the axis of the rotary prism vertical, and the 6° prism base up, in the slot toward the face, the false object is made to appear below the true, and if directly under it, there is lateral orthophoria. The rotary prism turned in either direction will make the false object go either to the right or to the left of the vertical line through the true object, which must be, at all times, the one looked at. Should the false object not be under the true, turning the rotary prism in the proper direction will place it there. On the face of the instrument toward the operator, can be read the kind and quantity of the error. The test for lateral orthophoria, in the near, is made by holding a card with a dot or cross in its center, at the reading distance. To test the vertically-acting muscles, the rotary prism must be turned so as to have the revolving screw vertical, and the axis horizontal. The 10° displacing prism, base in, must be placed in the slot towards the patient's face, so as to displace the image beyond the area of binocular fusion. The false object should be in the same horizontal plane with the true, if there is vertical orthophoria. Any movement of the rotary prism will displace the false object, either raising or depressing it. When the false object is not found on a level with the true, there is a vertical heterophoria. Turning the rotary prism so as to bring the

false object to a level with the true, shows, on the face towards the operator, the kind and quantity of the vertical error.

With the instrument in the adjustment for detecting vertical orthophoria, and without a displacing prism, the balance of the obliques is found by moving the rotary prism, first down, while the patient looks at a horizontal line until it doubles. The lines will be parallel if there is orthophoria of the obliques. Reversing the movement of the rotary prism, the false line appears above the true, but should be parallel with it. If there is not a perfect balance between the obliques it will be shown by a want of parallelism between the false and true lines. The kind of error will be indicated by the direction in which the lines converge, but the quantity cannot be measured by this instrument.

With the instrument still in the adjustment for the vertical muscles, sub-duction and superduction may be quickly determined, as by the Wilson phorometer. Adjusting it as for testing the lateral muscles, abduction can be taken without the aid of a supernumerary prism, if the patient is orthophoric. To take the adduction, one or two supernumerary prisms will have to be used to aid the rotary prism. If adduction is not above 25°, the 15° prism may be placed in the slot toward the face, with its base toward the temple. Turning the ro-

tary prism will add to the effect of the supernumerary prism up to 10°. This added to 15° gives 25° of adduction, provided the doubling occurs only at the end of the rotation. If the adduction should be 30°, or more, it can be shown by placing the 5° or 10° prism, base out, in the slot in front, while the 15° prism remains behind, and again moving the rotary prism through the nasal quadrant. This instrument can measure adduction only up to 35°. In testing for the adduction with the monocular phorometer, the only muscle to respond is the *one* internal rectus.

By reversing the instrument all of these tests can be repeated on the muscles of the left eye. In every one of these tests the image in one eye remains undisturbed. The object seen by this eye must always be seen by *direct* vision, while the false object must be seen by *indirect* vision.

The simpler methods of testing for orthophoria of the recti, even including the use of the Maddox rod, are all faulty and should be discarded. The leveling part of a phorometer is an absolute necessity, for without it there can be no exactness in the placing of prisms before an eye. In testing for lateral orthophoria, slight errors, resulting from an improperly-placed prism, could be tolerated, but not so in testing for vertical orthophoria. The Maddox rod is objectionable in all tests of the

recti for the reason that a part of the streak of light, whether it be vertical or horizontal, will fall on the field of binocular fusion, unless the error be great. The false image, whatever may be its character, should never be on any part of this field; otherwise a greater or less effort at fusion will be made.

There is a legitimate use for the Maddox rod. It is in testing the oblique muscles, both as to their orthophoria and their intrinsic strength. This instrument may be called the *cyclo-phorometer*, though Stevens has named the instrument he has invented for this purpose the *clinoscope*. The first of these instruments was invented by Price, in 1893, and was exhibited by him before the Section of Ophthalmology, at the meeting of the American Medical Association in San Francisco, in 1894. It consisted of a double prism, line of bases horizontal and a rod at right-angles to this line of union, placed in a circular disc to fit the rim of a trial frame, and a Maddox rod only to be placed vertically in the other side of the frame. Looking at a candle, the patient would see two horizontal and necessarily parallel lines of light with the one eye, and a single horizontal line of light with the other, the latter appearing between the other two, and parallel with them in orthophoria of the obliques. This was for testing the obliques when the visual axes were approximately paral-

lel. It was faulty in that there was no adjustment by means of which the frames holding the rods could be leveled. A little later, Baxter, of Boston, and Brewer, of Connecticut, each independently, invented a cyclo-phorometer, with the error in the Price instrument eliminated. Brewer, not knowing of the Price invention when he made claim for himself, later wrote to the Ophthalmic Record as follows: "Dr. G. H. Price, of Nashville, Tenn., appears in your July [1898] issue as claimant to prior use of the Maddox rods in testing the position of the retinal meridians. Since he very clearly substantiates his claim, so far as I am concerned I tend him such laurels as I may have grasped, and trust he may wear them securely and gloriously." Dr. Brewer named his instrument the *torsiometer*. Later than this Stevens brought out his prism clinoscope, the construction of which is not very different from the instruments of Baxter and Brewer.

The cyclo-phorometer must, of necessity, be a binocular instrument. The cyclo-phorometer, Fig. 9, made for use in connection with the monocular-phorometer stand, or the Wilson phorometer holder, consists of a base on which rest two graduated cells (E), in each of which is to be placed a triple Maddox rod (H) with the axis vertical. Behind each of these circular cells is a rectangular cell (F) for a displacing prism. There is an arrange-

ment (D) by means of which the pupillary distance can be easily regulated so that the one streak of light may be brought directly under the other. There is beneath the base of the instrument, a spirit level (L) for regulating

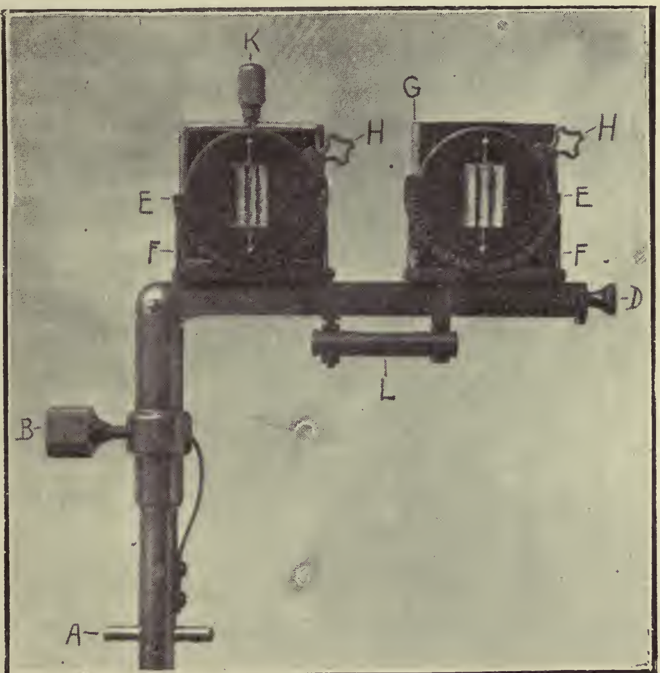

Fig. 9.

the adjustment of the instrument. On each disc containing the rods is marked below a line continuous with the axis of the central rod. The rods placed vertically, with a prism of 5° base up behind one of them, will show two

horizontal lines of light, when a candle is looked at. The lower one will be seen by the eye before which is the combination rod-and-prism. The lines should be parallel, and their ends even. The latter can be regulated by turning the screw (D) that controls the pupillary distance. The slightest movement of either disc will cause a loss of parallelism of the streaks of light. If not parallel, there is want of orthophoria of the obliques, the kind and quantity of the error being shown by the rotation of either disc.

By removing the displacing prism, the intrinsic power —the cyclo-duction—of each oblique muscle can be taken alone, and then the combined cyclo-duction of either both superior or both inferior obliques. This is done, when only one muscle is being tested, by revolving the one rod in the temporal arc for a superior, and in the nasal arc for an inferior oblique. If both superior obliques are under the duction test, then both rods must be revolved in the temporal arc; if both inferior obliques, then both rods must be revolved in the nasal arc. The moment the two streaks separate, the rotations must stop. On the arc of the cell the extent of cyclo-duction can be read. The normal cyclo-duction for a single oblique muscle is somewhere between 7° and 14°. The combined cyclo-duction of either pair of obliques is somewhere between 12° and 22°.

The method of determining the perfect balance of the oblique muscles, or the imbalance when it exists, by the Stevens clinoscope, will be better understood after a description of the instrument itself. This description is given in the words of the inventor:

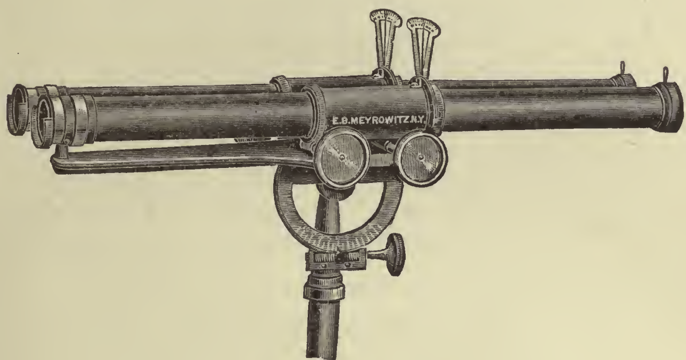

Fig. 10.

"The clinoscope [Fig. 10] is composed essentially of two hollow tubes, each of which has at one end a minute pin-hole opening through which the eye can look, and at the other end a translucent disc on which is drawn a line, in the case of one tube from the centre straight up, and in that of the other tube straight down.

"These tubes are so adjusted on a standard that they can be placed and maintained in the same horizontal plane, which is indicated by a spirit level, but from end to end they can be directed horizontally or up or down.

They can, as above intimated, be made to converge or diverge to meet certain contingencies.

"The tubes rotate on their long axes, and a pointer attached to each tube indicates on a scale the extent to which the tube is rotated. The small sight openings are so adjustable that the distance between them may be suited to the interpupillary distance of different persons. For the accommodation of those who, on account of presbyopia, myopia, or any high degree of refractive error, cannot see at the distance of the test objects from the eyes, there are clips in which refracting glasses may be placed. The sight openings being very small and exactly in the same horizontal plane, there can be no doubt as to the erect position of the median plane of the head when the two eyes are seeing, each through its appropriate sight opening, any existing hyperphoria being corrected.

"The instrument is to be so adjusted in respect to height that the sight-holes will be on a level with the eyes of the examined person when sitting erect. This is best accomplished by the use of an adjustable table. The tubes may be exactly parallel or they may, in certain cases, be made to converge very slightly, thus making the distant point at 8 or 10 feet instead of infinite distance. Under other exceptional circumstances they may be made to diverge. The tubes

must be brought to an exact level with each other as shown by the spirit level.

"Unless the subject of the examination is unable to see the test lines of the tubes, on account of presbyopia or high refractive error, no glasses should be used, and when glasses are necessary the weakest that will enable the person to see the lines clearly should be placed in the clips. A prism for the correction of hyperphoria may also be required. *The glasses should not be worn*, since, if a strong glass should not be held exactly at right-angles with the axis of the tube, the lens would itself induce a declination of the image.

"The examiner must be sure that the examined person sees through both openings simultaneously, and that the view of both images is maintained throughout the examination; otherwise there can be no certainty that the head is precisely erect.

"When the examined person has secured a good view of both the test lines, he should endeavor, if they do not at once unite, to induce them to do so as in a stereoscope. Some people do not succeed in this, in which cases the examination may go on with the images separated, but it is less satisfactory.

"When the apparent vertical position of the lines has been attained, the examiner should move them more or less backward and forward, in order that the true posi-

tion may be more positively located. Few people can arrive at a satisfactory conclusion regarding the position of the lines at the first trial, but after a day or two the tests become, for nearly all intelligent people, remarkably uniform."

With the clinoscope thus adjusted, the head of the pin with the point up should be fused with the head of the pin whose point is down, and both pins should be vertical if the oblique muscles are doing their full duty—if the vertical axes of the eyes are parallel with the median plane of the head. If the two pins are not now one vertical line there is a cyclophoria. Whether the cyclophoria is plus or minus is easily determined, and its quantity is measured by revolving the tubes till the two pins become one vertical line.

In determining cyclo-duction by the clinoscope, the translucent discs with lines entirely across are to be used instead of those that have the lines only half way across. With the tubes properly adjusted the two lines would be seen as one. Revolving one tube would tend to displace the image of one line, which the eye would overcome by torsioning, as long as possible. The conclusion which Stevens has reached is that the image may be displaced as much as 14° in one eye before doubling occurs, and that the combined displacement, in opposite directions, of the images in the two eyes, may be as much as

22°. He also claims that a little greater displacement may be overcome by the inferior obliques than by the superior.

No test for orthophoria is complete until the verting power of the recti has been determined.

In the study of the field of fixation, or, better, the field of rotations, it must not be confounded with the field of vision which, in healthy eyes, is much larger than the former. The rotations in the four cardinal directions are those to be studied; and the best means at our command for this study is the tropometer, invented by Stevens. A fair degree of accuracy may be obtained by the use of the perimeter and a lighted candle, or a small electric light, in a dark room. This method, though not the better of the two, will be described first. The patient should be placed in front of the perimeter as for the taking of the field of vision. The eye to be tested must be in the center of the perimeter curve. The extent of the outward rotation is determined by asking the patient to fix the blaze of a small candle, or a small electric light, as it is moved behind the arm of the perimeter, toward the temporal side of the eye under test. When the patient can turn the eye no further out, the operator putting his open eye (one eye should be closed) in line with the candle and the center of the rotated cornea, observes the image of the candle reflected from the center

of the cornea, and then reads the number of degrees marked at the point of location of the candle. In like manner the extent of rotation of the same eye in the opposite direction is determined and noted. The arms of the perimeter are now to be placed in the vertical position, when the extent of the upward and downward rotations can be measured in the same way. There is no necessity for other than these measurements in the four cardinal directions. Muscles found capable of making these rotations reach the standard, will be fully capable of doing the work of effecting any other rotation, which, after all, must be a combination of the forces effecting the cardinal rotations. Both eyes should be thus tested.

The Stevens tropometer, shown in the accompanying cut, Fig. 11, is an instrument of greater precision and is more convenient for use. The arrangement for fixing the head needs no description, since it is easily understood. At the base of the instrument is a thumb-screw by means of which the tropometer proper can be placed at varying distances from the patient's eye. The object of this arrangement is to so adjust the instrument that the reflected image of the cornea will extend from one of the darker lines in the scale, to the other one, and this adjustment should be made at the beginning of every examination. Near the center of the upright piece there is a thumb-screw for elevating or depressing the

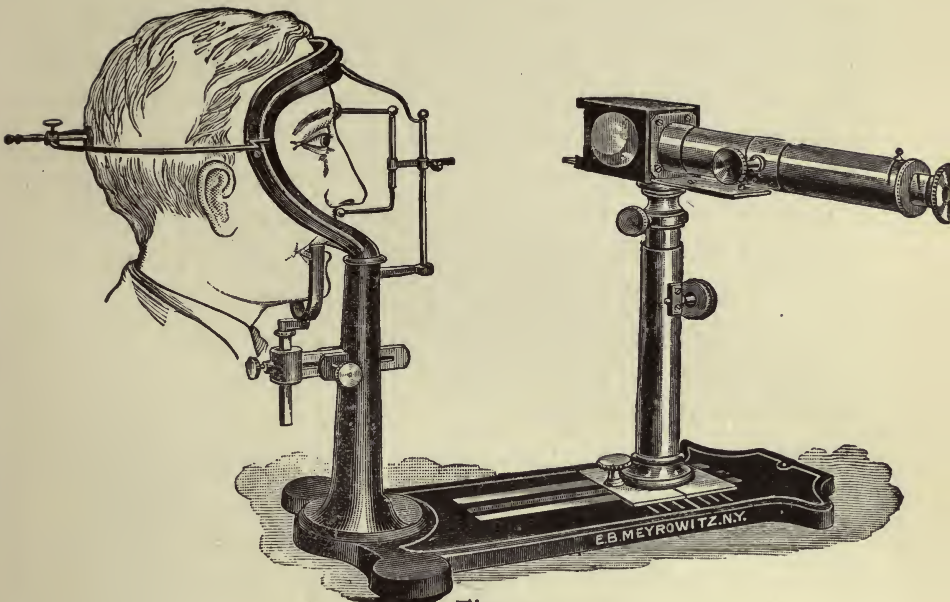

Fig. 11.

mirror so that its center may be on a level with the patient's eye. At the top of this upright there is a flat base by means of which the mirror-box of the tropometer may be placed directly in front of the eye to be examined. This is effected by simply sliding the tropometer in either the one direction or the other. The horizontal part of the tropometer is a little more difficult to understand, and yet it is simplicity itself. It consists of a square box, closed completely by metal on all sides except the one facing the patient, and in the center of this

side is an opening which is filled with a disc of perfectly plane transparent glass, in the center of which is a white dot at which the patient is directed to look, at the beginning of the examination. Inside of this box is the mirror, placed at an angle of 45° on a vertical axis. From this mirror the patient's eye is reflected, an aerial image of which is formed on the graduated disc, so that the operator at the other end of the instrument may see it. The sharpness of the image is regulated by the thumb-screw in the center of the telescope part, by means of which the lenses contained in the tube are so adjusted as to enable the operator to get perfect sharpness of outline of the aerial image. The disc containing the graduated scale has been constructed with mathematical correctness. In the center of this disc there is a heavy line extending entirely across. At right-angles to this base-line there extends from each side a heavy line, the distance between the two being nearly 60°. On either side of the base-line there are lighter lines placed at points 10° apart. When the handle of this disc is vertical, the position is for measuring superversion and sub-version. With this instrument adjusted so the patient's cornea extends from one heavy line to the other, the base-line passing down through the center of the cornea, and the image itself being sharply focused, we take the superversion by asking the patient to look up as

far as possible. In the reflected image the eye appears to move downward, for the image is inverted. The position of the lower margin of the cornea (upper of image) is now noted and the extent of the rotation is read off on the scale. In a normal condition the superversion should be 33°. This having been noted, the patient is asked to look straight forward again, when the image of the cornea will extend from one heavy line to the other as before, while the base-line will pass directly down through the center of the pupil. Now the patient is asked to look down as far as possible. Unless the upper lid is held up by external force, it will so cover the cornea that the measurement cannot possibly be taken. An assistant is necessary then to elevate the upper lid in order that subversion may be taken. While the patient is looking down as far as possible, the position of the upper margin of the cornea (lower as it appears in the image) is noted, and the extent of the rotation is read off on the scale. This should be about 50°. The superversion and subversion having been taken, the handle connected with the scale-disc is turned from the vertical to the horizontal. Now the instrument must be so adjusted that the base-line will coincide with the horizontal meridian of the cornea, while the cornea itself extends from one heavy line to the other. If the left eye be under test, abversion is taken by asking the patient to look as far towards the

left as possible. The location of the nasal margin of the cornea, when the eye is in extreme abversion, is noted on the scale and the extent of the rotation is read off. This should be about 50°. This done, the patient is asked to look straight forward, when the instrument is adjusted as before. Now he is asked to look as far towards the right as possible, when the extent of the adversion can easily be determined. This should be about 50°. The power of rotation in the four cardinal directions having been found normal, it would be correct to conclude that rotation in any one of the oblique directions would also be normal. Any marked variations in the different versions from the standard, as noted above, should be considered a very important guide as to any surgical procedure to be resorted to, but this will be more clearly set forth in the study of heterophoria. Both eyes should be thus tested.

The candle method of simply watching the eye as it rotates in each of the four cardinal directions, does not commend itself as being at all accurate; and yet it is better than no examination to determine the extent of these rotations. Unless the temporal rotation carries the outer margin of the cornea to the external canthus, and the inner rotation carries the inner corneal margin to the internal canthus, it would appear that these rotations are too limited. In the upward and downward ro-

tations there are only the lid margins, themselves movable, to give us an approximate judgment as to their extent. This method is of use in a case of paresis or paralysis, but it ought never to be relied on for other purposes.

The extent of these rotations, as given by different authors, varies but little. Landolt makes the standard of these rotations as follows: Out, 46°; in, 44°; down, 50°; up, 33°. Stevens places the standard as follows: Out, 48° to 53°; in, 48° to 53°; down, 50°; up, 33°. The standard set by Stevens is probably more nearly correct. A knowledge of an excess of, or deficiency in, these measurements can but be helpful when the question of a muscle operation presents itself. The rotating power of a muscle should never be reduced by operation below the standard measurement for that muscle.

The importance of the study of the field of rotation should not lead to a disregard of the field of binocular fusion. The latter can be determined only by the use of prisms. In this study again, it is not important to find the extent of the field except in the four cardinal directions. Authors differ as to the extent of this, while none of them sufficiently emphasize its importance, in the study of heterophoria. The accompanying cut, Fig. 12, shows approximately the shape and size of this field of fusion. When an image is displaced by a prism to any

point within the field, while the image in the other eye is on the macula, an effort at fusion will be made, and if the muscle that must respond is sufficiently strong, fusion will at once take place, caused by such a rotation as will bring the macula under the displaced image. When the image is thrown, by a stronger prism, entirely outside of the field of fusion, the guiding sensation,

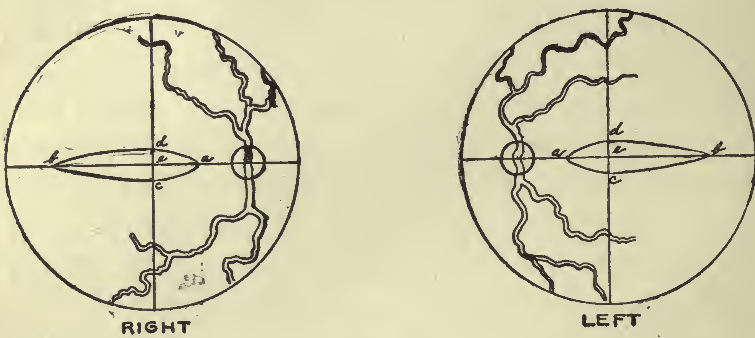

Fig. 12.

which seems to reside in this area only, will not call on any muscle to move the eye for the purpose of fusion. The nasal limit of this retinal area, as measured by a prism in front of the eye, is 8°; the temporal limit, 25°; the upper limit, 3°; and the lower limit, 3°. The line drawn through these four points marks the entire boundary of the field. This may be considered the normal size of the fusion area. In some cases it may

appear to be smaller, while in still other cases it may be larger.

It is by means of prisms which displace an image within this field that we can determine the fusion power of a muscle. This may be termed the intrinsic or lifting power of the muscle. A determination of this power is important, even in the study of orthophoria, but of much more importance in the study of heterophoria. A knowledge of the fusion power, associated with a knowledge of the verting power of a muscle, is indispensable in the formation of a judgment as to what ought, or ought not, to be done in an operative way, in any given case of heterophoria.

The power of the recti muscles for fusing images, expressed in prism degrees, is for the internus (adduction), 25°; for the externus (abduction), 8°; for the superior rectus (superduction), 3°, and for the inferior rectus (subduction), 3°. A muscle that has the normal fusion power should also possess the normal verting power; and when the one is abnormal the other is likely to be abnormal also. The standard of the fusion power of the recti might safely be set a little lower than that given above, for all except that of the internus. A fusion abduction of 6° and a sub-duction and superduction of 2° or 2½° may be considered as favorable.

If all the muscles respond correctly to the diplopia

test; if the duction power of the recti and the obliques reaches the standard; and if the verting power of the recti does not fail short, then there is sthenic orthophoria. Such a patient needs no help for his ocular adjustments.

Asthenic Orthophoria.

There is an orthophoria that is not in strength, but in weakness. The diplopia tests may elicit responses indicating orthophoria of all the pairs of muscles, but these muscles may show a want of duction power, also a want of verting power. Such eyes, though orthophoric, as judged by the diplopia tests, cannot be as strong as they would be if the muscles were possessed of full intrinsic power. If an externus perfectly balances its antagonistic internus and there is an abduction of only 4°, there must be a correspondingly low adduction. If there is harmony between the superior and inferior recti, and they show a superduction and sub-duction of only 1°, there is weakness that demands attention. Such cases are often met in actual practice. The treatment is ceiling-to-floor and wall-to-wall exercise. The method of carrying out this exercise is both simple and efficient. The patient is directed to stand against one wall of his room, midway between the walls to the right and left. Having previously fastened, by pin or tack, a piece of paper on each wall to right and left, at an angle of 35°,

approximately, and on a level with his eyes; and having placed some object on the floor immediately in front of him and at a distance equal to his height, he must stand with his head erect while he looks up at the ceiling where it joins the wall in front of him, then down at the object on the floor, and so on for six or eight movements in the vertical plane; then he must change his movements to the horizontal plane, looking first at the paper to the right, then at the paper to the left, and so on for six or eight movements in this plane. He then passes again to the vertical plane, changing the point of view rhythmically every three seconds; and, at regular intervals, alternating the vertical and horizontal movements. He should stop the exercise always short of fatigue, and should not continue it longer than ten minutes at a time. Once a day is often enough to resort to the exercise. The time of day for the exercise may be suited to the convenience of the patient. The duction power should be taken at intervals of a few weeks, and the exercise should be continued until the recti show the normal lifting power. In this way an *asthenic* orthophoria may be converted into a *sthenic* orthophoria.

The alternate contraction and relaxation of the recti, under the stimulus of the first, second. fourth, and fifth conjugate innervations, if not carried to excess, can result only in the up-building of the muscles. Since every

muscle is exercised in the same way and to the same extent as its antagonist, there is no danger of interfering with the equal balance that existed between the muscles before the exercise was commenced.

There are cases in which there is a sthenic lateral orthophoria and an asthenic vertical orthophoria. In such cases the ceiling-to-floor exercise alone should be advised. There are other cases in which there is a sthenic vertical orthophoria and an asthenic lateral orthophoria. In these cases only the wall-to-wall exercise should be given.

Since the strength of opposing muscles is correspondingly increased, there is never any danger of accomplishing too much. A lateral orthophoria with an abduction of 12° and an adduction of 36°, is a better condition than when the abduction is 8° and the adduction is 25°. A vertical orthophoria with sub-duction and superduction of 5° is better than if these ductions were only 3°.

The diagnosis between sthenic and asthenic orthophoria should always be made.

CHAPTER III.

HETEROPHORIA.

Heterophoria is a generic term and includes all errors of tendency of all the extrinsic ocular muscles. It is the disposition on the part of a muscle, or muscles, to disobey the law governing it; that is, the supreme law of corresponding retinal points. To obey this law, the recti, in the final result of their action, are concerned only with the visual axes; the superior and inferior recti of the two eyes keeping these axes in the same plane, the external and internal recti causing them to intersect at the point of fixation. The obliques must keep the vertical axes of the eyes parallel with each other and with the median plane of the head. In orthophoria the demands of this law are easily met; in heterophoria the demands are met, but not with ease; there is strain or overwork.

In heterophoria involving the superior and inferior recti, there is a disposition on the part of these muscles not to keep the visual axes in the same plane, the visual axis of one eye tending above the plane that ought to be common to the two axes, while the visual axis of the

other eye has a corresponding tendency downward. The direction of this tendency gives name to the error: upward tendency, hyperphoria; downward tendency, cataphoria. In heterophoria involving the lateral recti, there is a tendency toward intersection of the visual axes between the observer and the point observed, or they tend to intersect beyond the point of view, or even to become divergent. The tendency to cross too soon is esophoria; the tendency to cross too far away is exophoria. In heterophoria involving the obliques, there is either a tendency on the part of the inferior obliques to cause the vertical axes to diverge from each other above, or of the superior obliques to converge these above. The former is properly termed *plus cyclophoria;* the latter, *minus cyclophoria.*

Heterophoria has its causes, and just as certainly has its consequences. To exist in any one of its several forms, one muscle must have an advantage over its antagonist; or, what is the same thing, in reverse order, one muscle must be at a disadvantage as compared with its antagonist. The difference may be in the comparative sizes of the two muscles, the one being larger, and, therefore, stronger than the other. There may be a difference in the insertions of the two muscles, the one being too near the corneo-scleral junction and the other too far back. These muscles may be of proper size, but

it is certain that the one with insertion too far forward will exert more power in rotating the globe than its antagonist not so favorably attached. It must also be conceded as possible that one muscle of proper size as compared with its antagonist, and with no more favorable attachment, is more powerful than its antagonist because of an excess of nerve impulse sent to it. Whether the one cause exists alone, or whether two or more of them combine in the production of heterophoria, the error is corrected by an extraordinary nerve impulse which is sent to the weaker muscle of a pair, and thus, with the undue expenditure of nerve force, binocular single vision is maintained.

Orbital Malformations.

As has been claimed by Stevens, Risley, and others, malformation of the orbits may be a cause of heterophoria. Such malformation can be the direct cause of vertical and lateral errors, but not of errors of the obliques. As is shown in Chapter I., ideally-constructed orbits are such that the eyes they contain, when in the primary positions, will have their horizontal planes lie in the fixed horizontal plane of the head. As already defined, this fixed horizontal plane must necessarily be at right-angles to the median plane of the head. It may be said always to pass through the optic

chiasm. Thence anteriorly it should pass through the centers of origin of the externi and interni of both eyes; thence on through the centers of rotation of the two eyes. Posteriorly this plane passes, approximately, between the cerebrum and cerebellum, just as the median plane of the head passes between the two halves of the cerebrum.

In the chapter on hyperphoria and cataphoria will be found illustrations showing how an orbit that is too low will contain a cataphoric eye, while an orbit that is too high will contain a hyperphoric eye.

If the two orbits are neither too high nor too low, but only too far apart or too close together, it is hard to see how any form of heterophoria could result; yet it is possible that a lateral error might be thus caused: an exophoria when the eyes are too far apart, an esophoria when they are too close together.

However interesting may be the study of malformation of the orbits as causative of heterophoria, the treatment, whether operative or otherwise, must be directed to the muscles; since it would be utterly impossible, by manipulation or operation, to convert a malformed orbit into an ideal one. It stands to reason that prisms in positions of rest would be the ideal treatment of heterophorias dependent on orbital malformation, there being no muscle imbalance *per se*.

To Stevens, of New York, is due much credit for his pioneer work in the study of the ocular muscles. Before him, Graefe, in his study of insufficiency of the interni, gave us a glimpse of that light which Stevens afterwards turned on more fully. By means of the phorometer which he invented, he found it much easier to investigate the recti muscles. He prosecuted this study for many years, almost alone, and under fire of most severe criticism. The information given us by Graefe about insufficiency of the recti muscles is so incomplete, as compared with the results of Stevens' labors, that the latter may well be looked upon as the discoverer of these conditions. The remarkable feature of Stevens' work is that he so long ignored any study of the oblique muscles, which have a duty to perform no less important and exacting than that required of the recti. It has already been shown that the obliques, under the influence of four conjugate innervations, must keep the vertical axes of the eyes parallel with each other and with the median plane of the head. As far back as 1891,* it was shown that the obliques were not always capable of accomplishing their work with ease; and a little later the method of exercising these muscles so as to strengthen them, was introduced.† In 1893 it was

* See Archives of Ophthalmology, Vol. XX., No. 1.
† See Ophthalmic Record, Vol. II., No. 1.

shown that one danger attending an advancement of a rectus muscle was that its new attachment might be so displaced as to throw unbearable work on one or other of the obliques.* Again, in 1893, following a suggestion by Swan M. Burnett that one or more of the recti might naturally be so attached that the obliques would be insufficient for the work demanded of them, an operation on a rectus for strengthening an oblique muscle was suggested.† It was not until 1895 or 1896 that Stevens commenced his study of the obliques. Soon thereafter he invented his clinoscope, the capabilities of which will be fully shown in the discussion of cyclophoria. His work in this direction, as might have been expected, has been helpful; but in his paper published in the January (1899) number of the Archives of Ophthalmology, he claims entirely too much credit for himself, as expressed in these words: "Anomalous declinations not related to disabilities of the muscles had, previous to my own contributions,‡ obtained no recognition as a practical subject, if, indeed, it had been recognized at all, although it is probably one of the most practical of the various important phases of the adjustments of the eyes."

In the matter of nomenclature Stevens gave us perfect terms, but not a complete list. There should be a

* See Ophthalmic Record, Vol. II., No. 9.
† See New Truths in Ophthalmology, 1893, pp. 40, 41.
‡ Not earlier than 1897.

name for every deviating tendency, but he gave none for the downward tendency. In conformity with his nomenclature, the downward tendency of an eye has been named *cataphoria.**

Before Stevens began the study of the obliques, the name *cyclophoria* was given to insufficiency of the obliques, in conformity with the nomenclature applied to the recti. To distinguish insufficiency of the superior from insufficiency of the inferior obliques, the term *plus cyclophoria* has been applied to the former and *minus cyclophoria* to the latter. Maddox, for some reason, preferred the terms *plus torsion* and *minus torsion.* Still later Stevens gives to these conditions the names *plus declination* and *minus declination.* Unless there is a very special reason for doing otherwise, there should be uniformity in the nomenclature applied to the ocular muscles. As there appears no valid reason against this uniformity, the term *cyclophoria* alone will be used in the chapter on errors of the obliques.

Terms should be multiplied only when there is absolute need for them. The terms *anaphoria* and *kataphoria* added to nomenclature by Stevens a few ago, and applied, respectively, to an upward tendency of both eyes and the reverse, a downward tendency of both eyes, would tend only to confusion. These conditions exist,

* See New Truths in Ophthalmology, 1893, page 68.

but it is far better to say *double hyperphoria* and *double cataphoria*.

Maddox did good work when he offered as substitutes for *sursum-duction* and *deorsum-duction* the simpler and easier terms *super-duction* and *sub-duction*. But even these terms should be given only a single meaning. They should be made to apply only to the power the superior and inferior recti have for overcoming prisms in the interest of binocular single vision. Likewise *adduction* and *abduction* should be restricted in meaning so as to apply only to the interni and externi in their efforts to overcome the lateral displacing of images by prisms.

The fact that it is better to have two terms, each with a single meaning, than to have one term with two very different applications, must be the author's apology for adopting the following nomenclature for the turning of the eyes in the four cardinal directions: *Abversion*, turning the eye out; *adversion*, turning the eye in; *superversion*, turning the eye up; and *sub-version*, turning the eye down. These terms are shorter and better than *outward rotation*, *inward rotation*, *upward rotation*, and *downward rotation*.

Duane deserves credit for his very careful study of the ocular muscles in his little brochure, "Motor Anomalies of the Eye;" but the terms *hyperkinesis* and *hypo-*

kinesis, introduced by him, are not nearly so simple or easy as the terms *sthenic* and *asthenic esophoria*, *sthenic* and *asthenic exophoria*, and *sthenic* and *asthenic hyperphoria*, and so on for all the phorias. The meaning, however, is precisely the same.

The heterophoria that is purely innervational should be designated by the prefix *pseudo* as *pseudo-esophoria*, a condition depending on the relationship existing between accommodation and convergence, and not dependent on any error inherent in the interni.

The following is a list of the heterophorias:

(1) Esophoria, of which there are two varieties, viz.: pseudo-esophoria and intrinsic esophoria. Of the intrinsic variety there are two kinds, sthenic and asthenic.

(2) Exophoria, pseudo and intrinsic. Of the intrinsic variety there are two kinds, sthenic and asthenic.

(3) Hyperphoria and cataphoria, which are always intrinsic when the superior and inferior recti are the only factors. These errors are either sthenic or asthenic. There is now and then to be found a double hyperphoria or a double cataphoria.

(4) Cyclophoria, plus and minus, both pseudo and intrinsic. The intrinsic variety may be either sthenic or asthenic.

Two or three of these errors may be found combined in many cases; but it is probably better not to have

compound names for such combinations of errors, as it is important that the quantity of each error should be noted. It would be difficult to indicate the quantity of the two errors if the note was made *hyper-esopohria* or *hyper-cyclophoria*.

Tests.

There are some interesting tests for heterophoria that can be made, in a rough way, independent of the phorometer. One is the cover test. If there is an error of any magnitude, it will manifest itself on covering one eye while the patient is looking with both eyes at a test object twenty feet distant. The covered eye will immediately place itself in a state of equilibrium. When the cover is removed, it will return to the position of harmony with the fellow eye. This readjustment can be easily seen, in many cases, by the observer. The direction in which the eye moves when uncovered indicates the kind, but not the quantity, of the heterophoria. A patient of keen observation will be made conscious of the disturbance. This is better done by covering and uncovering the eyes alternately. In high degrees of heterophoria a plane red glass placed before one eye will suspend, to some extent, the effort at fusion, and diplopia will result. A candle should now be the test object. The position of the red blaze, the patient the

while looking at the real candle, will indicate the kind of error. Only the higher errors respond to the red-glass test.

The test by means of the phorometer, preferably the monocular instrument, for the reasons given in the chapter on orthophoria, is the only one to be relied upon. By it the kind of error is quickly determined and the quantity is easily measured. In testing the interni and externi, the 6° prism is placed, base up, in the cell next to the eye. This will throw the false image above on the retina and entirely outside the field of binocular fusion, so that no attempt can be made at fusion. The false object will be below the true, and will bear that relationship to it determined by the existing imbalance. The handle of the rotary prisms must be horizontal, the index at zero, and the instrument perfectly level. The true object must be the one looked at. If the false object is toward the opposite side, there is exophoria. Turning the controlling screw, the index is moved toward the corresponding side until the patient says the false object is directly under the true. The number at which the index stands marks the quantity of exophoria for that eye.

If the false object, instead of being on the opposite side, shows itself on the corresponding side, the existing error is esophoria. The controlling screw is now turned

so that the index moves toward the opposite side. The revolution is stopped when the patient says the false object is in a vertical line with the true one. The number at which the index stands shows the quantity of esophoria for that eye.

The test having been made for the distance, it should now be repeated at the reading point. The test object now should be a white card in the center of which is a black dot, and the card should be held directly in front of the eyes. There should be no line drawn vertically through the dot, as advised by Graefe, for the reason that this line would cross the area of binocular fusion, and would thus lead to an attempt, on the part of the eye, to correct its error. The kind of error is determined and its quantity is measured, as in the distant test. The result, not always the same as found in the distant test, should be noted.

The lateral error having been thus found and measured, the 6° prism should be removed and the 10° prism, base toward the nose, should be placed in the cell; the handle of the rotary prism should be placed vertically, and the index must be made to stand at zero. It is now of vast importance that the instrument shall be perfectly level; otherwise, a vertical error may be shown when none exists. The instrument thus adjusted, any vertical imbalance may be detected and measured. As in the

test for lateral errors, the true object must be the one fixed. The false image will be thrown outside the area of binocular fusion, toward the nose, while the false object will appear on that side of the true, corresponding to the eye under test. If the false object is below the horizontal line passing through the true, there is hyperphoria of that eye, the quantity of which is determined by revolving the controlling screw so that the index shall move upward. The number at which the index stands when the patient says the two objects are level shows the quantity of the error.

If in the test the false object is above the horizontal line passing through the true, there is cataphoria of that eye. The screw is now turned so that the index shall move downward. The number at which the index stands, when the patient says the objects are level, shows the quantity of the cataphoria. The test for vertical imbalance need not be repeated at the near point.

The one eye having been tested thus for imbalance of all the recti, the instrument should now be turned into position before the fellow eye, that the lateral and vertical imbalances it may have may be found and measured. Usually, if there is esophoria of one eye, the other will also show esophoria; the amount in the one is about equal to that in the other. Occasionally, however, there will be a difference of 1° or even more. The same may

be said of exophoria. When there is hyperphoria of one eye, the other is usually cataphoric, and the one error is about equal to the other.

A double hyperphoria and a double cataphoria cannot so easily be shown, in the imbalance test, by the phorometer. The proof test, which is by means of the Maddox double prism, quickly shows either of these errors when they exist. The base-line of these prisms (4°) should be held horizontally before first one eye and then the other, having each eye look at the distant test object, first through the upper prism and then through the lower, observing that position which throws the double objects closer together. If they are closer for both eyes when the false object is seen through the upper prism, there is double hyperphoria; but if they are closer for both eyes when the false object is seen through the lower prism, there is double cataphoria.

It can be readily understood that, if there is hyperphoria of one eye and cataphoria of the other, the two objects will be closer together when the false one is seen, by the hyperphoric eye, through the upper prism, and by the cataphoric eye when seen through the lower prism. Hence the reason for calling this use of the double prism the proof test of hyperphoria and cataphoria.

The next step in the testing is to determine the ability

of the obliques to parallel the vertical axes of the eyes with the median plane of the head. This can be done rudely in any one of several ways: First, by means of the Maddox double prism, the object looked at being a horizontal line on a blackboard, twenty feet distant, or a horizontal line on a card held at the reading distance; preferably, both. The base-line of the double prism (4°) should be horizontal and so held before one eye as to double the test-line. The two lines seen by this eye must be parallel. The third line, seen by the other eye, should be between the other two and parallel with them. A dipping of the true line toward the opposite side would show a plus cyclophoria, while a dipping toward the corresponding side would show a minus cyclophoria. The quantity of the error thus shown, however, cannot be measured.

The same test may be made by means of a single prism of 4°, base up or down, before the eye; but even still more easily it may be made by the revolving prism in position for taking the sub-ducting and superducting power. The rotation, of course, must be carried beyond the possibility of fusion. The false line is seen by the eye before which the single prism is held or the rotary prism has been placed, while the true line is seen by the other eye. The refracting angle of the prism points in the direction of the false line. When this line is seen

below, by the right eye, and the ends of the two toward the right converge, there is plus cyclophoria; if they diverge toward the right, then there is minus cyclophoria. There is no method of measuring the error thus found. In revolving the rotary prism or in turning the single prism so as to make it possible for fusion to take place, it is interesting for the patient to watch the manner of fusing; if there is cyclophoria, the two lines will come together at one end first and then quickly fuse throughout.

The Stevens clinoscope will detect and measure any existing cyclophoria; but the best instrument for detecting cyclophoria and measuring the amount of the error is the cyclo-phorometer. It is much cheaper than the clinoscope, and, better still, it is simpler in construction and much more easily manipulated. The 5° prism, base up, behind one rod gives the second streak of light; the thumbscrew makes it easy to place the one streak directly under the other—ends even. If the axes of the rods are at zero and the two streaks are not parallel, cyclophoria is positively shown; if the lower streak is seen by the left eye and the two streaks converge at the left, there is plus cyclophoria; but if they diverge at the left, there is minus cyclophoria. The extent of the turning of the rod on the one side or the other, necessary for paralleling the streaks, measures the quantity

of the cyclophoria. It is not necessary, with the cyclo-phorometer, to keep in mind the fact that the lower streak is seen by the eye that has the displacing prism before it, for the position of the axis of the rod at the time the streaks are made parallel names the error as well as measures its quantity: when the axes must be moved into the nasal arc, there is plus cyclophoria; into the temporal arc, there is minus cyclophoria.

The spirit level of the cyclo-phorometer enables one to determine if the cyclophoria is monocular or binocular. When the two streaks of light converge at one end or the other, if the error is binocular, neither of the lines will be horizontal. If one is horizontal while the other is oblique, the error is monocular; if both lines are inclined in the same direction, it shows plus cyclophoria in one eye and minus cyclophoria in the other.

Having followed out the tests already described—the tests for imbalance—one knows the kind of error or errors in the individual case, but remains ignorant of the character of these errors. The duction and version tests alone can reveal the fact that an error is sthenic or asthenic, just as the study of the refractive errors alone reveals whether or not a given heterophoria is pseudo or intrinsic.

The duction test is to determine the power the muscles have for overcoming the displacing of images by

means of prisms. To this meaning the word *duction*, with its several prefixes, should be restricted. The method of determining duction power by means of the monocular phorometer has already been set forth in Chapter I. It can be accomplished by means of the prisms in the refraction case, but not so quickly nor so accurately. Duction is wholly an involuntary act, and it is accomplished through the guiding sensation, in obedience to the law of corresponding retinal points; but it has its limitations. Abduction is the power of an externus to fuse with the image on the macula of the fellow eye, an image that has been displaced to the nasal side of the macula of its own eye. Less than 6° of such power is subnormal; more than 8° is supernormal. Adduction is the power of an internus to move the macula outward until it shall stand under the image that has been displaced temporally, so that it may be fused with the image on the macula in the fellow eye. It is certainly subnormal if less than 18° to 25°. The adduction stimulus is much greater than any other, and is much more variable. Its variableness makes it less reliable than any other duction; but, nevertheless, it must be known in dealing intelligently with esophoria.

Superduction is the power the superior rectus has for fusing an image displaced below the macula, with the

image on the macula in the fellow eye. Less than 2° is subnormal; more than 3° is supernormal.

Sub-duction is the power the inferior rectus has for fusing an image displaced above its macula, with the image on the macula in the fellow eye. Less than 2° is subnormal; more than 3° is supernormal.

In all duction tests it is better that the image should be slowly moved away from the point occupied by the macula, when the eye is in the primary position, toward the boundary line of the field of binocular fusion, which should be considered as immovably fixed. So long as this image is within this field there is binocular single vision, for the macula moves with the moving image as far as possible; but the moment it passes the border line there results diplopia. The index of the rotary prism marks the duction power of the muscle concerned. It should be noted. The field of binocular fusion is larger if the muscles are stronger, smaller if the muscles are weaker. Its size can be changed both by exercise and by operations. If it is too small, it may be increased by exercise and by shortening and advancement operations; if too large, it can be reduced only by tenotomies, which should always be partial.

Cycloduction, which is involuntary, can be taken only by the clinoscope or the cyclo-phorometer. With the former instrument the line as seen by one eye is turned by

means of the proper screw up to the point of doubling. The index marks the torsioning power of the oblique involved. With the cyclo-phorometer the axis of one rod is moved from zero toward the nose to test the torsioning power of the inferior oblique, and toward the temple for determining the power of the superior oblique. An oblique should have a fusing power of from 7° to 10°. The inferior oblique has a little greater fusing power than the superior oblique.

In determining the several ductions the tests should be monocular.

In any given heterophoric condition the duction test, aided by the version test, determines whether the error is sthenic or asthenic, and, therefore, the kind of operation, if any, that should be performed. No muscle whose duction power is normal or subnormal should be weakened by a partial tenotomy; but the imbalance should be cured either by a shortening or an advancement of its still weaker antagonist.

No examination of the recti muscles is complete without the taking of the verting power of every one. As shown in Chapter II., this can be rudely done by simply watching the eyes while the patient looks as far as possible in the four cardinal directions. The objection to this test is that there is no accuracy in it, and yet it is better than no test. The reason for introducing the

terms *adversion*, *abversion*, *superversion*, and *sub-version* has been given already, and the extent of each, considered as normal, has been shown in the same connection. Of all instruments for making the version tests, the Stevens tropometer stands first, because of simplicity, accuracy, and speed. The only part of the instrument that should be dispensed with is the head rest, and this for two reasons: First, it interferes with the manipulation of the upper lid, when the sub-version is being taken, for now the lid must be held up or it will entirely obscure the cornea; second, it obscures too soon the small electric light or other test object which the patient should fix as the superversion is being taken. The mouthpiece is necessary in order to insure that the patient's head shall not turn while the verting power of the eye is being taken.

A fairly good substitute for the tropometer is the perimeter, if properly used. There should be some means for preventing the movement of the head, and nothing could do this better than a mouthpiece, such as constitutes a part of the tropometer. The eye under test should be in the center of the perimeter curve. As with the tropometer, the rotations should be taken in the four cardinal directions only. With the arms of the perimeter in the horizontal plane, abversion and adversion can be easily taken; and if proper care is observed,

the result will be practically accurate. The small electric light, shaded toward the observer, should be placed first directly in front of the eye while in the primary position. From this position, the light, while being kept in contact with the perimeter arm, should be moved in the temporal arc—the arc for abversion—slowly, the patient fixing the moving light, while the operator fixes its image reflected from the center of the cornea, moving his own head harmoniously with the moving light. The patient should speak when he finds himself no longer able to fix the light. At the same moment the observer can see that the image is no longer reflected from the center of the cornea. Thus the patient serves as a check to the operator, while the operator also serves as a check to the patient. When 5° beyond the point of fixation, the small light becomes so blurred that the patient can easily detect the change; hence, if the patient is closely observant, there is small room for error. The operator cannot so easily detect an error of 5°, as shown by the reflected image. For these reasons the subjective part of the test is more reliable than the objective. The position of the light on the arc, when the patient can no longer fix it, and when the reflected image begins to leave the center of the cornea, indicates the degree of abversion. With the light moving along the nasal arc, adversion is taken in like manner, and its extent should be noted.

With the arms of the perimeter rotated into the vertical plane, superversion and sub-version are taken by moving the light along the upper and lower arcs, respectively, and their extent is noted. In taking sub-version, the reflected image cannot be so easily watched, even when the upper lid is held out of the way. Here the subjective part of the test must be relied upon.

One eye having been thus tested, in the four cardinal directions, the other eye should be properly placed and the various duction powers should be determined and noted.

Unlike the duction power, which is involuntary, version power is a thing of volition. Neither one should be depended on to the exclusion of the other. The result of these two tests (duction and version) should be compounded, if the surgeon would be safely guided in his operative work, or even in the non-operative treatment of heterophoria.

Cycloversion has no existence, since voluntary rotation around the visual axis is impossible.

No muscle whose ducting or verting power is normal or subnormal should be weakened by a partial tenotomy. No muscle should be increased in strength by an advancement or by a shortening when the duction and version are not subnormal.

Symptoms of Heterophoria.

That there are cases of heterophoria without symptoms must be conceded, but such cases are not often seen by the ophthalmic surgeon. It is a symptom, or symptoms, of eye-strain that drives the patient to the doctor. It may be that the symptoms, in a given case, are dependent in part, if not wholly, on errors of refraction; but it is a serious mistake to suppose, as some do, that eye-strain is always and only associated with the ciliary muscle. The ciliary muscle is only one of eight muscles connected with each eye; and each of the seven other muscles, when called on to do abnormal work, is just as capable of developing symptoms. People who have no symptoms, and yet have heterophoria, are possessed of a stable nervous system and are physically strong. The physically weak and the nervously unstable must be sufferers from eye-strain, of whatever character. The nervous centers of the one may be compared with the steady leaves of the oak, which are shaken only by a wind; while the nervous centers of the other may be compared to the leaves of the aspen tree, which quiver in the slightest zephyr. Or, again, the easily-disturbed nerve centers may be compared to the leaves of the trailing little vine seen in the old turned-out field; all the leaves of which fold themselves up, if but one leaf be touched by a human finger.

The strong, healthy person, with a stable nervous system, may never have had a symptom resulting from muscle or focal errors that have always existed. Let this individual have an attack of typhoid fever, measles, or other depressing disease, or let her pass through a pregnancy and confinement; now, on attempting too soon the use of her eyes in near work, she begins to be a sufferer. The suffering becomes a habit, and she gets no permanent relief until the focal or muscle error has been corrected.

A sudden shock to a nervous system that has been strong, brings about a change that ever after makes the patient feel the effects of errors whose existence before made no impression.

Growing children, especially those that are delicate, when too hard pressed in their school work, almost invariably present some one of the many symptoms of strain. More women than men feel the effects of muscle and refractive errors, mainly because of the fact that the former are forced to spend a greater number of hours every day in near work, than the latter. Bookkeepers, or men who are engaged in other continuous near work, are often forced to seek aids to vision.

HEADACHE.—The most common of all the symptoms caused by heterophoria is headache. The aching may be in the temple, brow, at the top of the head, over the

parietal region, or in the back of the head. In some cases the suffering is in the back of the neck. The pain may be on both sides of the head, but often it is unilateral. It is periodic in character, and usually comes on as the result of prolonged, hard near work. The headache which one has on awaking in the morning—or, more properly speaking, the headache which awakens the patient—is usually due to disturbances in the sinuses, or cells, that open into the nasal passages, brought about by mouth-breathing, the mouth-breathing depending, of course, on nasal stenosis. Rest in sleep usually relieves the headache of heterophoria and of refractive errors. Headaches due to eye-strain, that come on unassociated with near work, are usually heterophoric, and not refractive. The headache that one has on bright days and when amid bright surroundings, as the white buildings and white walks of an exposition, is often due to overwork of a weak sphincter of the iris, which is compelled to keep the pupil small that the retina may be protected from the glare. The headache of eye-strain is usually of the nervous variety—that is, unassociated with nausea and vomiting. However, genuine sick headache—pure migraine—is sometimes caused by both refractive and muscle errors. The migraine which disappears as presbyopia comes on, proves itself clearly dependent on an error of refraction; and the same may be said of other

headaches that disappear as one grows old. Indeed, this coincidence should have attracted attention to focal errors as causative of headache long before anything was known on this subject.

Not so with headaches that are dependent on heterophoria, for strain of heterophoria once means strain of heterophoria throughout life, unless relieved by treatment, surgical or otherwise.

VERTIGO AND NAUSEA.—The kind of muscle error that is the most common cause of vertigo and nausea is insufficiency of the obliques to prevent cyclophoria. The correctness of this teaching is emphasized in cases of paresis of an oblique or of a superior or an inferior rectus, either one of which would be attended by a torsioning of the eyes. The earliest and most marked symptoms presented by these cases are vertigo and nausea, which continue so long as the patient tries to use both eyes. Excluding the vision of the affected eye, the symptoms vanish. When cyclophoria is the cause, these symptoms will be periodic, and will present themselves only when the weak obliques are no longer able to maintain perfectly the parallelism between the vertical axes of the eyes and the median plane of the head. Overwork, worry, shock, ill health, sleeplessness—all tend to make these symptoms worse.

CONFUSION OF THOUGHT.—Any one of the hetero-

phorias, whether associated with errors of refraction or not, necessarily interferes with that clearness of comprehension one would have if his eyes were free from all errors. Reading becomes a burden to heterophorics for the reason that their thought centers work confusedly, through sympathy with the motor centers that are overtaxed in efforts at harmonizing the ocular muscles. How far confusion of thought may be carried toward insanity, because of continued existence of a muscle error, remains to be shown. Cases of undoubted insanity have been cured by operations on the ocular muscles. It has been a matter of common observation that school children who were counted as dull and incapable, not able to comprehend clearly either books or teachers, have been transformed into apt scholars by ocular treatment. In the race for an education, a child who has any form of heterophoria, or an error of refraction, is considerably handicapped.

Chorea.—A spasmodic condition of the muscles of the face—a local chorea—in children with unstable nerve centers, is often caused by eye-strain, as is shown by the quick relief that follows a correction of the condition causing the strain. The cause continuing to act, the transformation of a local into a more general chorea is often effected. It cannot be denied that chorea, sometimes in a very aggravated form, is caused by visual

errors; but it cannot be asserted that all choreas are caused by ocular defects. It is safe and proper to say that every child suffering with chorea should be examined by an ophthalmic surgeon with the view of having any existing ocular error adjusted. It is generally considered that, whatever may be the cause, chorea is a reflex neurosis, and that finding and removing the cause brings a speedy cure. Medical treatment, without reference to cause, is at best slow.

EPILEPSY.—There can be no longer any room for doubt that, in many cases, epilepsy, whether in the severe or in the light form, is often reflex in origin. If wax impacted in the ear can be the cause of epilepsy, is it unreasonable to suppose that hyperopia may cause this motor-psychic disturbance? But it is no longer a matter of supposition; for, beyond all question, many cases of epilepsy have been cured by the convex lenses that corrected the focal error. If a phimosis can excite epileptic seizures, is it any wonder that the excessive tension of muscles, in cases of heterophoria, may now and then be the cause of these attacks? In fact, scores of epileptics have been cured by operations for the establishment of normal equilibrium between the ocular muscles. Hundreds of other cases would have been cured, before now, by partial tenotomies and advancements, if the principles underlying heterophoria had been properly

understood. The proportion of cases of epilepsy caused by heterophoria may not be large—no one knows—but every case of epilepsy should be subjected to a most careful examination of the visual apparatus, by a competent investigator; and all focal errors found should be corrected and muscle imbalance should not be ignored. That Stevens, Ranney, and others have spoken their convictions, based on observation and practical experience, on this subject, the author believes. He himself has had and has cured some cases, while failing on others. In the light of no distant future, the statements that have been made by Stevens and Ranney will not appear to be so extravagant as some now judge them. Of all the apparently extravagant statements, this one is taken from "Ranney on Nervous Diseases," page 481: "One of the most remarkable cases that ever came under my observation was that of a combination of chorea, epilepsy, and idiocy, in a girl about eleven years of age, who completely recovered her health, strength, and mental faculties, when a refractive error in her eyes was corrected by glasses and a serious combination of muscular defects in the orbit was adjusted by tenotomy. This case was one that I saw some three years ago, in connection with the practice of Dr. Stevens. At the first examinition, the child could not walk without being supported on both sides, drooled constantly, talked unintel-

ligibly, answered questions with apparently little conception of their import, could hardly sit unsupported in a chair on account of chorea, had epileptic seizures repeatedly during the day and night, and presented a pitiable and apparently hopeless aspect. I saw her about a year after the operations were performed, at the request of Dr. Stevens. I found her free from chorea and epilepsy, able to run and skip a rope unaided, rosy cheeked, and in full possession of her mental faculties." Who can wonder that Ranney, having observed this remarkable case, has become a firm believer in the reflex character of functional neurotic troubles?

It is not remarkable that the refractive error was detected and measured in this case, but it must have been exceedingly difficult to arrive at a correct understanding of the complicating heterophoria. The phenomenal results that followed but emphasize the importance of the early removal of the cause, before molecular changes in both the motor and psychic areas of the brain shall have become unalterably fixed.

That epilepsy should be caused by abnormal tension of the delicate ocular muscles is certainly no more wonderful than were the results of some experiments made by Drs. Dercum and Parker, of the University of Pennsylvania, as published in the Journal of Nervous and Mental Diseases, in 1884. Some of the subjects of ex-

perimentation were placed by a table, which they barely touched with the tips of the fingers of one or both hands. "The fingers were not allowed to rest on the table, but were maintained, by constant muscular effort, barely in contact with it." Some of these subjects, in from a few minutes to an hour, first became tremulous and then violently convulsed, falling to the ground. The oftener the experiments were repeated on the susceptible subjects, the more easily were the convulsions induced. Abnormal muscular tension, in persons with unstable nerve-centers, caused these convulsions, which must have been very much like epileptic attacks. Those experimented on who had stable nerve-centers did not show violent symptoms, but, judging from that part of the report published by Ranney, page 463, lighter symptoms must have shown themselves, even in these cases. Other experiments showed that severe, long-continued thought, fixed on one thing, excited direct trouble in the psychic centers, and, sympathetically, disturbed the motor centers, resulting in convulsions.

If the result of the experiments made by Dercum and Parker had been more generally known, there would be fewer to doubt that severe functional neuroses may be caused by abnormal muscle tension in cases of heterophoria and errors of refraction. No other muscles of the body have such a wonderful nervous endowment as

the muscles (extrinsic and intrinsic) of the eye. Each of the twelve external muscles and each of the four muscles inside the two eyes has its individual nerve-center, and, besides these, there must be at least nine or ten conjugate nerve-centers. Only the eye muscles must work with mathematical precision so as to have sharp images and binocular single vision. Any necessity for overaction —abnormal tension—on the part of any ocular muscle should be counteracted, if the delicate nervous system is to be freed from a prolific source of disturbance that may be either psychic, motor, sensory, or visceral.

The emphasis given above is not intended to impress the reader with the idea that the orbit is Pandora's box, out of which come all functional ailments. Undue excitation of the brain-center controlling any organ of the body can reflexively disturb other centers near by and remote—centers psychic, centers motor, centers sensory, centers controlling the viscera. It would be well for humanity, if all other organs and parts of the body could be so thoroughly and scientifically investigated as can the eyes.

CATALEPSY.—If clonic muscular contractions, associated with unconsciousness, can be caused by errors of refraction and heterophoria, the same errors may cause tonic muscular contractions—rigidity—with mental oblivion. The cause should be sought and, when found,

removed. Occasionally excessive tension of the ocular muscles is causative of catalepsy.

Hysteria.—This disease is one of the terrible functional neuroses, and, like the others already considered, may depend on focal errors and imbalance of the ocular muscles. The character of the hysteria in a given case does not point to any definite cause. Whether the manifestations are sensory, motor, psychic, visceral, or vasomotor, a cure can be effected, if the cause can be found; hence the importance of a most thorough investigation of these unfortunates. In these cases no investigation is complete that leaves out the visual apparatus. Errors of focus should be corrected, imbalanced muscles should be adjusted, with the fair prospect that at least some will be cured.

Neurasthenia.—This condition of weakness of the neuron elements is the very opposite of those just considered, and yet it may have the same cause. If errors of refraction and heterophoric conditions do not cause neurasthenia in certain cases, it must be conceded that they can perpetuate it in all cases. The results of the correction of errors of refraction, and the regulation of the tension of the recti muscles by tenotomies and shortenings or advancements, have been so marvelous as to justify the declaration that every subject of neurasthenia should have the visual apparatus investigated.

The correction of any existing errors, to say the least, would tend to hasten a cure, whatever may have been the chief cause. Many cases have been speedily cured by these means alone, in which internal medication, electricity, and rest had been tried in vain. In any case in which but little nerve force is generated, the undue expenditure of that little should be prevented, thus giving medicine, food, and rest a better chance to have full regenerating power restored to the weak brain cells. In no case should the correction of visual errors be wholly relied on, but other organs and parts of the body should be investigated, and all local diseases found should be treated—such as those of the stomach, the rectum, the bladder, the ovaries, and the womb; for these may have been the chief cause of the prostration, the visual errors having served only to aggravate and perpetuate the neurasthenia.

Through the nervous system, errors of refraction and heterophoria may cause functional derangement of the thoracic, abdominal, and pelvic viscera. Indigestion, torpidity of the liver, and constipation have disappeared, in some cases, as a result of the correction of visual errors. A case of stammering was unexpectedly cured by the wearing of prisms prescribed, by a Denver oculist, for an exophoria. The Doctor was so astonished at the result that he decided to remove the

prisms, so that he might determine whether the cure was a coincidence or a consequence, a *post hoc* or a *propter hoc*. The stammering returned, and was again relieved by the wearing of the prisms. Disturbed respiration and an irritable heart have been quieted by lenses and by operations on the eye muscles. Dr. Hale, of Nashville, once had a little patient suffering from a refractive error, whose bladder was so irritable that micturition in sleep was almost a nightly occurrence; but at the time of the examination of the eyes nothing was told the Doctor about the irritable bladder. Later the parents reported that the glasses had done more than was contemplated, in that the irritability of the bladder had vanished. The Doctor's astonishment was great. He decided to settle the question of relationship between the wearing of the glasses and the disappearance of the irritability of the bladder, by withholding the glasses. Almost immediately the bladder trouble returned, to disappear again, and permanently, when the spectacles were restored to the child.

It has been a matter of common observation that dismenorrhœa in girls and young women has been wholly or in part relieved by a correction of errors of the visual apparatus. These things are marvelous and can be explained only by assuming that these remote organs have *sympathized* with the eyes in their efforts to correct

errors of adjustment and errors of focus. To claim that all cases like those referred to above have the exciting cause in the eyes would be absurd; but when the cause is so simple, how easy and rapid the cure! So far the symptoms considered have been in parts more or less remote from the eyes. In many cases the only symptoms of eye-strain are in the eyes themselves or in their appendages.

ASTHENOPIA.—This is a weakness of the eyes that may be shown in a sense of fatigue associated with more or less pain in the eyes, together with an excessive secretion of tears, whenever an attempt is made to do near work. Letters, while being looked at, may fade away for a moment, because of relaxation of weak ciliary muscles; the page may become blurred or mixed from side to side, because the imbalance of the lateral recti muscles momentarily increases the angle of convergence, as in esophoria, or by the temporary lessening of this angle, as in exophoria; or the blurring may be from top to bottom, caused by the sudden elevation of one visual axis above the other, as in hyperphoria.

The conjunctival vessels often become congested because of visual errors. Likewise the lid margins become engorged with blood, scales forming among the roots of the lashes, and the nutrition of the lashes themselves suffering. In high degrees of muscle imbalance, objects

in the distance sometimes become double momentarily. Not only may the external structures of the eyes become congested because of strain to overcome errors, but the structures within the eyes also may become congested. Functional disturbances without and within the eye, if long continued and much aggravated, may lead to organic changes and even result in the development of some of those diseases that bring blindness.

One of the most troublesome asthenopias presents itself when a patient is exposed to bright light, either natural or artificial, and is caused by a weak sphincter of the iris, which must keep the pupil small so as to protect the delicate retina.

Treatment of Heterophoria.

The treatment of heterophoria must be determined by the kind and quantity of the error. Small errors of the recti may be treated by prisms in positions of rest for the too weak muscles. The base of the prism must always point toward the muscle to be favored. In esophoria the base would be out, and prisms of equal strength should be placed before the two eyes.* If the error is small and the interni are properly attached, or even if they are attached in greater part above the horizontal plane, in

* Exceptions will be shown in the chapter on Esophoria.

most cases they can be comfortably worn. If they do not give comfort, it becomes evident that the interni are attached too low, and that their forced action develops a plus cyclophoria, which becomes a source of discomfort. In exophoria the prisms should be of equal strength before the two eyes,* and their bases should be in. If the error is small and the externi are correctly attached, the rest prisms would certainly bring comfort, at least for a time. If the externi are attached too low, the prisms, as a rule, can be comfortably worn; but if they are attached too high, the use of the prisms cannot bring comfort because of the plus cyclophoria developed.

In hyperphoria the correcting prism, in nearly all cases, should be worn only in front of the hyperphoric eye, the base being placed down, for the reason that the action of the superior rectus for overcoming the prism develops a minus cyclophoria, which, to a certain extent, neutralizes the plus cyclophoria which nearly always exists. In the rare cases in which there is minus cyclophoria, the rest prism should be placed, base up, before the cataphoric eye, that a neutralizing plus cyclophoria may be caused. Only when there is perfect balance of the obliques would it be correct practice to divide the prismatic effect between the two eyes, base down before the hyperphoric eye, base up before the cataphoric eye. The

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* Exceptions will be shown in the chapter on Esophoria.

per cent of cases accepting kindly the rest prism, base down before the hyperphoric eye, is very large; while only a very small per cent of such cases would be improved by placing the rest prism, base up, before the cataphoric eye. A full prismatic correction of a hyperphoria should be given only when there is a marked complicating cyclophoria.

In uncomplicated cyclophoria, the patient may be benefited by wearing a weak pair of cylinders, axes in the arcs of distortion for the stronger muscles, even when there is no astigmatism; or, if there is astigmatism, by displacing the axes of the correcting cylinders in the arcs of distortion for the stronger pair of obliques. As will be shown in the chapter on cyclophoria, the arc of distortion by plus cylinders for the superior oblique of the right eye has its center always at 45°, and for the left eye it has it at 135°; while the center of the arc of distortion by plus cylinders for the inferior oblique of the right eye is always at 135°, and for the left eye it is at 45°. The reverse is true of minus cylinders. These arcs are equal in extent only when the astigmatism is vertical or horizontal, but their sum is always 180°. The extent of the displacement of the axes of the cylinders, requisite for the relief sought, depends on the quantity of cyclophoria and the strength of the astigmatic correction—a weak cylinder, more displacement; a strong cylinder,

less displacement. If there is no complicating hyperphoria, the displacing effect of the cylinders should be divided equally before the two eyes; but if there is a hyperphoria complicating a plus cyclophoria, only the cylinder before the cataphoric eye should be displaced; while the reverse would be true when a hyperphoria complicates a minus cyclophoria. It is clear that the enforced action of an inferior oblique would elevate the corresponding eye, to that extent neutralizing or correcting the cataphoria; while the enforced action of a superior oblique would correspondingly depress the eye to which it belongs, thus diminishing, if not correcting, the hyperphoria. The displaced cylinders do for the weak obliques what rest prisms do for the weak recti. In both instances the law of direction is infringed, which, in itself, is not good. For this reason it is better practice to relieve all forms of intrinsic heterophoria either by exercise or by operations. An objection applies to displaced cylinders that does not apply to prisms: by the former vision is rendered less acute, while by the latter there is no such interference.

Gymnastic Exercise.

In low degrees of heterophoria, of whatever kind, development of the weaker muscles by exercise is the best practice. The time necessary for curing these cases by

exercise and the trouble involved in carrying it out regularly and systematically, constitute the chief objections to this method of treatment.

What the author wrote in 1893 so perfectly harmonizes with his present views on the exercise of the ocular muscles that it is reproduced in the few following pages:

The development of the ocular muscles, by means of gymnastic exercise, has received but little attention from modern authors. Noyes devotes about one page to the subject; DeSchweinitz, less than one page; Schmidt-Rimpler, three lines, as follows, "No improvement is to be expected, as a general thing, from exercise of the interni; overexertion, that is apt to occur, may result, on the contrary, in a serious impairment of their power;" Fuchs, not a line; Berry, not a line; Meyer, ten lines; Landolt, not a line; Wells, one paragraph of ten lines; Schweigger, not a line; Nettleship, not a line; Juler, not one word; Carter, not a line.

Those of the twelve authors above named who teach anything on the subject teach the same thing. This teaching is illustrated by the following quotation from DeSchweinitz: "Thus, to exercise the interni [in exophoria] a prism of 10° is placed, base out, before one eye, and as soon as the diplopia produced is overcome, 5° more are added, and so on until the limit of adductive

power is reached. . . . These exercises should be repeated every day for ten or fifteen minutes at a time, until the patient has acquired the power to overcome readily a prism of 50°." He recommends the same character of exercise for developing the externi, beginning with a 3° prism and increasing to 8°.

Noyes, following Dyer, who wrote on this subject in 1865, says: "He [the patient] takes a candle flame or door knob at twenty feet for his object, and performs the efforts of adduction and abduction by means of these prisms. He begins, say, with adduction, and at first holds the prism of 5°, with base out, before one eye; then substitutes the 10°; then before the other eye places 5°, making a total of 15°; then, if practicable, substitutes the other prism of 10° for the 5°; and so climbs up the ladder of adduction prisms by such steps as he can make. If the interval of 5° becomes too great, he may take that of 2½°." He speaks of the exercise of the externi after the same plan, using weaker prisms with their bases in. He directs that the exercise be continued ten minutes at each sitting, and that it be repeated not oftener than twice a day, until, in case of the interni, a prism of 42½° can be readily overcome, and, in the case of the externi, a prism of 10°. The prism of maximum strength having been reached, its use should be continued, says this author, once daily for a time. Noyes closes by saying: "A de-

cided gain in comfort and use of the eyes may be obtained by this proceeding; and if this result is not adequate, the true state of the muscular relations is brought to view."

It is not necessary to make further quotations in order to bring clearly into view the character of the exercise. It is the object of this paper to show that the plan is unsound in principle, and must necessarily be unsuccessful in practice. Continuous muscular contraction, augmented at short intervals, for ten minutes, or for even five minutes, may show what a muscle is capable of doing in an emergency; but it is not calculated to build up or develop the inherent power of the muscle.

In a modified form Dr. Charles E. Michel, of St. Louis, has persistently practiced the development of weak internal recti muscles by means of prisms, since 1877. The prisms used by him have not been stronger than 4° nor weaker than 1°. Beginning with the weaker prism, he directs the patient to exercise frequently (ten to fifteen times) during the day, each period of exercise to last only four or five minutes for the first few days; later they are to be worn only four or five times daily, increasing the time of exercise by two to five minutes daily, until they can be worn comfortably one hour. When the patient, looking in the distance, becomes able to wear the 4° prism one hour without discomfiture, he

is directed to commence reading. At first he must read only from three to five minutes at a time; but later he increases this time by two to five minutes daily, until he can read comfortably one hour, four times a day. Whenever this can be done, the patient is directed to continue for several months the reading-exercise practice for from a half to one hour, two or three times a day. To suit individual cases, modifications as to strength of prism and length of time and frequency of exercise must be made.

Under Dr. Michel's treatment, fully 60 per cent of his patients have full muscular power developed, and in this way are enabled to use their eyes with comfort; 25 per cent have greater or less gain in comfort; while 15 per cent derive no benefit from the treatment. As a preliminary step to the muscle treatment, the Doctor always corrects any existing refractive errors, and has the patient wear these lenses behind the exercise prisms.

Dr. Michel's method of developing ocular muscles is given for the reason that it differs essentially from that set forth in the books, and for the additional reason that a high percentage of cures results from his method. The Doctor's success has been due to the fact that his weak prisms used made but little demand on the weak muscles, thus making it possible for the continuous contraction to be borne and the muscle strengthened.

In contrast with Dr. Michel's practice, the method of Dr. George T. Stevens, of New York, is here given in his own words: "Adduction may be greatly improved by gymnastic exercises of the interni, by means of prisms. In these exercises the eyes are required to unite images in overcoming gradually-increasing obstacles. A prism of a few degrees, perhaps 10°, is placed, base out, before one of the eyes, while gazing at a lighted candle at twenty feet distance, when an effort is at once made to prevent diplopia. As soon as the images are blended, another prism, of perhaps less degree, is placed in the same manner. The images being united, a stronger prism takes the place of one of those already in place, or one is added to those already in position. Thus, little by little, the eyes are required to overcome prisms until the images can no longer be united. Then all the glasses are removed and the process is repeated; with each repetition something may be gained. The exercise should not be continued, at a single sitting, more than five or six minutes; and only a single sitting daily is desirable. By this means the adducting power can, in most cases, be raised, after a few exercises, to the desired point.

"The effect of such exercise upon the eyes is very often extremely salutary. With greater freedom of muscular action comes a sense of relief from nervous strain, which is often of a most gratifying character. Such an

exercise is in no way related to the practice sometimes adopted, and which should be condemned, of requiring the patient to gaze for a long time at a near object.''

The virtue of Dr. Michel's method lies in the fact that, though he taxes the muscles for a long while, gradually reaching the maximum of time, he taxes them but slightly, using only weak prisms; while the virtue of Dr. Stevens' method lies in the fact that, though he taxes the muscles severely, using the strongest prisms possible, reaching the maximum strength by degrees, he does not continue the exercise very long and does not repeat the sitting again the same day. And, too, he almost strikes the right principle in his method of intermitting the exercise. In contrast with both of these methods, and with the methods laid down in the books, the method of

Rhythmic Exercise

will now be given, the author feeling confident that it is founded on sound principles and that it, therefore, can be carried out successfully in practice.

Contraction and relaxation, alternating in short and rhythmic order, and continued short of fatigue, is the kind of exercise that *develops* a muscle in any part of the body. It is the alternate contraction and relaxation that develops the muscles of the arm of the blacksmith. If

the forearm should be flexed on the arm and held in that position ten minutes, no one would suppose that the muscles concerned could be developed thereby. There would be greater reason for believing that such action would enfeeble the muscles. This is precisely the kind of contraction effected by prisms in the old method of exercising the recti muscles. There can be no wonder that better results have not followed, and that the practice has been abandoned by almost all oculists.

It would be of little worth to condemn the old practice as bad without setting forth a new line of practice, based on sound principles, and one that must be successful, in suitable cases.

While rhythmic contraction and relaxation, regulated as to intensity and time, will develop any one of the recti muscles, as is developed the biceps of the blacksmith's arm, the writer would not be understood as believing that one of these muscles can be developed out of a *low* state of weakness into a *high* state of strength. There are cases of exophoria that will remain exophoric still, in spite of long-continued rhythmic and graduated exercise; and these cases, to be cured at all, must be cured either by partial tenotomies alone or by these supplemented with rhythmic exercise. The same may be said of esophoria and of hyperphoria. Only low degrees (not more than 6°) of lateral heterophoria can be converted, by

rhythmic exercise alone, into orthophoria; the higher degrees can be corrected by partial tenotomies, shortenings, and exercise combined. While, in suitable cases, the aim of partial tenotomies and shortenings should be to approach orthophoria, yet the greatest care should be exercised not to go beyond the "balance" line. The safest thing is to leave, for correction by exercise, some of the original condition.

Any one of the recti and either of the obliques weaker than its opposing muscle, the difference in corresponding strength not being too great, may be developed by rhythmic exercise into a state that will enable it to work harmoniously with its fellow.

Exercise for Exophoria.

Exophoria may be taken first for study. The quantity should not be more than 6°. The internal recti are the muscles wanting in strength. There are two plans of exercise, rhythmic in their nature, by either one of which, or by both combined, these muscles can be perceptibly strengthened:

(1) The wax taper method;

(2) The method by prisms, bases out.

The exercise with the taper (small wax candle) must be conducted as follows: The patient is directed to light the taper and hold it at arm's length from, and on a

plane with, the eyes, immediately in front of the face. Fixing his vision on the flame, he continues to look at it while he brings it slowly to within seven inches of his eyes, holding it there about two seconds. He then closes his eyes for a moment (at the same time moving the candle to one side) and, on opening them, fixes his vision on some distant object. The same procedure is gone through with a second time, and so on for five to fifteen times at one sitting. The sittings may be repeated one or more times daily for weeks or months. The best time for this exercise is early in the morning, while the muscles are fresh from sleep. In many cases the morning sitting will be sufficient for the day. This is especially so if the exophoria is low in degree. Reading or other near work should not be done within the hour after the exercise is taken.

In this taper exercise no one can doubt that the guiding sensation compels the internal recti to contract, in obedience to the law of corresponding retinal points, as the light advances, the maximum of contraction being reached when the taper is seven inches from the eyes. On closing the eyes partial relaxation of the interni occurs (keeping the eyes closed long enough, the relaxation would become complete). The moment the eyes are opened and the vision is fixed on a distant object, in quick response to the guiding sensation, the relaxation

becomes complete. Thus is brought about contraction and relaxation, which should be discontinued short of fatigue. That this rhythmic exercise, properly regulated as to frequency and force, will develop the internal recti, is susceptible of demonstration on the part of any one who wishes to know the truth.

The second method for developing the interni is by means of prisms, bases out. The prisms to be used may be from 1° to 8°, and one should be placed before each eye. The treatment should be commenced with the weaker prisms, and as development of the muscles advances, the stronger should be brought into use. The object looked at should be a candle, lamp, or gas jet, fifteen to twenty feet distant. With the prisms before the eyes, the image in each eye is displaced out, when the guiding sensation calls quickly into action the interni for fusing them. After three seconds the interni must be allowed to relax for the same length of time (three seconds), which is readily effected by lifting the prisms up and allowing the light to enter the eyes uninfluenced. The guiding sensation at once causes the relaxation to take place, so that the yellow spots may receive the images. At the end of three seconds the prisms are again dropped before the eyes, when the interni again contract. Then a second time the relaxation is effected by lifting the prisms; and so on throughout every sitting, which should

last from two to ten minutes, but should always be discontinued short of fatigue. The sittings should be repeated two or more times a day. While it will take weeks, if not months, to establish orthophoria, nevertheless this end can be attained, in suitable cases, by this method. It may be better in most cases to resort to the two methods of development, the taper and the prisms, each day, but not at the same sitting.

In resorting to the prism exercise, it would be more convenient to close the eyes, for the purpose of getting relaxation, than to lift the prisms; but when the eyes are closed the relaxation is slow to take place, and is rarely complete at the end of sixty seconds; whereas, when the prisms are raised, the guiding sensation effects at once complete relaxation, which continues till the prisms are again placed before the eyes. The rhythmic nature of the exercise is more perfect in the latter than in the former, and results are better necessarily.

The method of exercise of the interni by means of strong prisms, introduced by Dr. Deady, of New York, and later reintroduced and earnestly advocated by Gould, may have its merits, but certainly not in the line of muscle building. The good resulting from this method must come through excitation of the converging center, that of the third conjugate innervation. An overdraft on a nerve-center may be endured for a time, but should be

avoided, if possible. Ultimately exhaustion would be expected to follow. At any rate, it would seem to be far better to change the condition of the muscles so that the normal nerve impulse would make them do their work properly. That a muscle can be made stronger by light rhythmic exercise, never carried to the point of fatigue, does not admit of a doubt. The muscular Sandow, capable of lifting many hundred pounds, developed his muscles by rhythmic exercise with three-pound dumbbells.

Without endorsing the use of strong prisms, in exophoria, the method must here be given. The exercise begins at a point twenty inches distant from a lighted candle or gas jet, by placing before the eyes the strongest prisms, bases out, that can possibly be overcome. At once the light is carried from the patient, or the patient recedes from the light, until a distance of twenty feet intervenes. The prisms are then raised, when, of course, relaxation occurs. When again within twenty inches of the light, the prisms are lowered, and recession follows as before. Thus the exercise is continued from three to five minutes, the powerful contractions and full relaxations following each other every seven seconds. The periods of exercise are to be repeated several times a day. Very strong claims have been made for this method, and there may be more in it than

would appear from reasoning about it; but its most ardent advocates confine its use to the treatment of exophoria.

Esophoria.

In this condition the muscles to be built up are the external recti. There is but one method for doing this, and that is by means of prisms. These should be from $\frac{1}{2}°$ to 3°, certainly not more than 4°, and their bases must be placed in. Beginning with the weaker prisms, the patient should look at the candle twenty feet distant for three seconds, during which time the guiding sensation has caused the externi to undergo contraction; and then the prisms should be held up for three seconds to allow relaxation to take place. These steps should be thus regularly repeated throughout each sitting of two to ten minutes, the sittings themselves being repeated two or more times daily, as in the treatment of exophoria. In suitable cases orthophoria can be brought about.

Hyperphoria.

Hyperphoria and cataphoria, like esophoria, are susceptible to exercise only by means of prisms. Given a case of left hyperphoria (right cataphoria) of not more than $1\frac{1}{2}°$, there is a possibility of developing vertical orthophoria by means of rhythmic exercise. The muscle on the left side to be developed is the inferior rectus,

and that on the right side is the superior rectus. The prisms used should vary from $\frac{1}{4}°$ to 2°; most cases will not require a stronger than a 1° prism. The base of the left prism must be up; that of the right prism, down. As in exophoria and esophoria, the patient should exercise from two to ten minutes at a time, and two or more times a day. The object looked at should be twenty feet distant, and it should be seen through the prisms three seconds, then without the prisms three seconds, and so on throughout each sitting. Thus contraction and relaxation of the weak left inferior rectus and weak right superior rectus are effected in rhythmic order. If the hyperphoria is on the right side (left cataphoria), the base of the right prism must be up and that of the left prism must be down, when exercising. In every form of heterophoria the apex of the prism must point in the direction of the muscle to be developed by it.

Occasionally cases present themselves in which there is a general weakness of the recti muscles, and especially of the external and internal recti, unaccompanied by general physical weakness. Such cases generally manifest esophoria for distance and exophoria in the near, neither muscle being able to overcome a prism of anything like the usual strength. To operate on such a case would be improper, since relief of the exophoria in the near would be attended by a corresponding increase

of the esophoria for distance, and *vice versa*. In such cases the interni should be brought under the influence of the rhythmic exercise, as already set forth in the study of exophoria, at one time of the day; and, at some other time of the day, like attention should be paid to the external recti, as in simple esophoria. In these cases strychnia and electricity could be used with some promise of aiding the exercise treatment. Such patients should be allowed to undertake but little near work, until the exercise treatment by means of prisms has become well advanced. In these cases the wax-taper treatment of the internal recti is not applicable until late in the course. These cases are far more stubborn than cases of simple exophoria or simple esophoria; and yet great advantage can be derived from the rhythmic exercise by means of weak prisms, aided by strychnia and electricity.

For cases showing esophoria in the distant test and exophoria in the near, adduction and abduction both being low, wall-to-wall exercise, probably, can accomplish more, in a shorter time, than the prism exercise referred to above. To perform this task the patient must stand against one wall of his room, equally distant from the walls on the right and left; previously there must have been pinned to the right and left walls two pieces of white paper, each at an angle of 35° from the patient

when in position for exercising, and as high from the floor as are his eyes. With his head in the primary position and his face directed toward the middle line of the opposite wall, he must stiffen his neck while looking first at one piece of paper and then at the other, changing from the one to the other with the regularity and interval of the tick of an old-time clock. This should be discontinued short of fatigue, and need not be prolonged over five minutes. It may be done once or twice a day. If exophoria in the near is 5° or more, the candle exercise may be resorted to once a day and the wall-to-wall exercise once a day. Since this method of exercise costs nothing, and the patient is more impressed with the fact that he is doing something, in many cases it is better to prescribe it than the prism method.

As in lateral, so in vertical, heterophoria, the imbalance may be associated with subnormal superduction and sub-duction. In such a case the prism exercise should be resorted to once a day for curing the imbalance, and the ceiling-to-floor exercise once a day, always short of fatigue, but never longer than five minutes. To do the ceiling-to-floor exercise, the patient must place himself as for the wall-to-wall exercise. A piece of paper, a spool of thread, or a pocketknife should be placed on the floor as far in front of the patient as he is tall. Fixing his head in the primary position, he is di-

rected to look first at the object on the floor, and then up at the junction of ceiling and wall, changing from the one point of view to the other, as in the wall-to-wall exercise.

Occasionally there will be both a lateral and a vertical imbalance with the duction power of every rectus below normal. In such a case the candle exercise for exophoria in the near, the prism exercise for the vertical imbalance, and the conjoined wall-to-wall and ceiling-to-floor exercise should be resorted to. In combining the wall-to-wall and ceiling-to-floor exercise, it is best done by looking, from four to six times, from wall to wall, and then, from four to six times, from ceiling to floor, continuing thus to alternate for not longer than ten minutes, but always short of fatigue.

In cases in which the recti muscles are weak, because of a low state of general health, no treatment should be thought of except that intended for the well-being of the whole system. Use of the eyes in near work should be prohibited until recovery of the general health has occurred.

Cyclophoria.

The treatment of insufficiency of the oblique muscles* is by means of cylindrical lenses (preferably convex), so placed as to lead the guiding sensation to demand con-

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traction on the part of the weak muscles. The +1.50 D. cylinder is the most useful, but a weaker one may be used at the beginning. One should be placed before each eye; and if the weak muscles are the superior obliques, their axes must be placed in the lower temporal quadrant, at first 15° from the vertical, when, because of slight retinal displacement of the object looked at, only a slight demand is made on the muscles, which should be kept up, in an intermitting way, for five minutes; then the axes should be revolved to 30° from the vertical, when, because of a greater displacement of the images, a greater demand for contraction is made on the part of the weak obliques, which should be kept up intermittingly for three minutes; now, lastly, the axes of the cylinders are revolved to 45° from the vertical, when the maximum displacement of the images occurs, and hence the maximum demand is made on the muscles, which should be continued intermittingly for two minutes only. As in the exercise of the recti by means of prisms, the best way to get contraction and relaxation alternately and in rhythmic order, is to lower and raise the frames containing the prisms every three seconds, so, to get rhythmic contraction and relaxation of the obliques under exercise, it is best to raise and lower the frames containing the cylinders every three seconds throughout the sitting. It is unfortunate for the con-

venience of the patient that the relaxation of ocular muscles does not quickly follow the closing of the eyes, since it would be much easier to open and close the eyes every three seconds than to lower and raise the frames at the same interval. The oblique muscles relax much more readily than the recti, on closing the eyes, but even these do not completely relax in the short time of five seconds.

In most cases of insufficiency of the obliques, exercising by means of cylinders once a day is sufficient; the best time for this exercise is before breakfast. The object looked at should be a horizontal black line on a white background or a white line on a black background, at a distance of ten feet. The cylinders should be properly centered.

What prisms are to the recti, cylinders are to the obliques. In either case the lenses correcting refractive errors should be worn during the exercise, in order that the best results may follow. The only exception to this rule is the wax-taper exercise of the internal recti, when no lenses should be worn.

Operative Treatment.

The heterophorias not curable by correction of errors of refraction, by prisms in position of rest, or by rhythmic exercise, should be subjected to operative procedure.

Such cases are not infrequent, and the relief from operations skillfully done is by no means uncertain. There is no department of surgery that requires more care in the making of the diagnosis. The condition of every extrinsic ocular muscle must be determined before any one muscle is to be operated upon. There are but two objects in view in muscle operations: the one is altering the tension of a muscle, the other is changing its plane of action. The tension of a muscle is to be altered either by a central partial tenotomy, as when operating on the too strong muscle; by shortening the muscle in the line of its original plane, or by advancing it straight forward, as when operating on the too weak muscle. In making either one of these operations, the existence of a cyclophoria must be first excluded. When there is a cyclophoria complicating any one of the other heterophorias, the operation on a rectus muscle should alter the tension of the muscle and, at the same time, change the plane of its action. In such a case a partial tenotomy should not be central only, but should include those peripheral fibers, a division of which would be corrective of the cyclophoria. A shortening should be done in such a way as either to raise or depress the plane of action of the muscle as might be indicated by the complicating cyclophoria. In making advancements, the new attachment should be carried either higher or lower than the

original attachment, as the character of the cyclophoria might determine.

The operation to simply alter the tension of a rectus muscle with the view of lessening its power is a central partial tenotomy. The operator should always be careful to leave a sufficient number of peripheral fibers to act as stay cords to prevent the cut muscle from retracting too much. The strength of the uncut fibers in both directions should be equal, so that the plane of the muscle may not be changed. Both judgment and skill must be exercised, else too much or too little of the tendon may be cut. It is better to aim at leaving some of the old error uncorrected than to transform it into the opposite condition. The conjunctiva may, but the capsule of Tenon must, be divided coextensively with the division of the tendon, to obtain the effect desired. *In no kind of heterophoria should a complete tenotomy ever be done;* but if by accident it should happen, the tendon should be stitched to the sclera directly behind the original insertion, and at that distance behind determined by a correct understanding of the exact character of the error for which the operation has been undertaken.

If a complicating cyclophoria is to be corrected by a partial tenotomy of a rectus, not only must the tension of the muscle be altered for the correction of the main

error, but its plane must be changed so as to correct the complicating cyclophoria. The kind of cyclophoria having been determined—and it is nearly always a plus cyclophoria—one is not left in doubt as to how the operation should be done. To cure a sthenic hyperphoria and a plus cyclophoria, the nasal and central fibers of the superior rectus of the hyperphoric eye should be divided, while the temporal fibers should be left uncut and sufficiently strong to prevent any over-correction of the hyperphoria; or the temporal and central fibers of the inferior rectus of the cataphoric eye should be divided, leaving the nasal fibers uncut and of sufficient strength to prevent an over-correction of the error.

In a partial tenotomy for a sthenic esophoria complicated with a plus cyclophoria, there being no hyperphoria, the lower and some of the central fibers of both interni should be divided, leaving the upper fibers uncut. In this way the tension of the muscle is altered, curing, wholly or in part, the esophoria, and the plane of each muscle is elevated so as to correct the plus cyclophoria. The plane of both interni having been equally elevated, there is of necessity developed a slight double hyperphoria—which, however, will give no trouble, being easily overcome by a pose of the head.

In operating on a case of sthenic esophoria complicated by a right hyperphoria and a plus cyclophoria, the

first operation must be done on the internus of the cataphoric eye, and should consist of a complete division of the lower and central fibers, leaving uncut the upper fibers of the tendon. The threefold effect of this procedure is a correction, in part or wholly, of the esophoria; a correction of the cataphoria; and a cure of the plus cyclophoria. Whatever part of the esophoria may remain after this operation should be corrected by a partial central tenotomy of the right internus. Should some of the right hyperphoria remain, but no cyclophoria, a partial central tenotomy of the right superior rectus should be done; but if there should remain some uncorrected plus cyclophoria as well as right hyperphoria, the inner and enough of the central fibers of the right superior rectus should be cut to cure these conditions. These three operations—sometimes even one or two of them—will cure a complicated case of this character.

If the esophoria is asthenic and uncomplicated, the operation of shortening should be done on one or both externi, and the plane of these muscles should be the same after as before the operation, otherwise a hypercyclophoria would be created.

If the asthenic esophoria is complicated with a right hyperphoria only, the externi should be shortened as though no complication existed, and later the hyperphoria could be treated by exercise, by a prism in position

of rest for the hyperphoric eye, or by a central tenotomy of the superior rectus of the hyperphoric eye. In such a condition no muscle plane should ever be changed. The plane of a muscle should never be changed unless there is a cyclophoria to be corrected.

If the asthenic esophoria should be complicated with a plus cyclophoria alone, not only should both externi be shortened, but the plane of each should be depressed so as to cure both the esophoria and plus cyclophoria.

If the asthenic esophoria is complicated by a right hyperphoria and a plus cyclophoria, the first operation should be on the externus of the hyperphoric eye, and should be a shortening so done as, at the same time, to depress the plane of its action. The triple effect will be to cure, more or less completely, the esophoria, the right hyperphoria, and the plus cyclophoria. If the left externus must be shortened for a remaining esophoria, whether complicated or not by a cataphoria and plus cyclophoria, one or both, for obvious reasons the plane of this muscle should not be altered. If the plane were elevated, it would lessen the cataphoria, but would increase the plus cyclophoria; if the plane were lowered, it would decrease the plus cyclophoria, but would increase the cataphoria. After the straight-forward shortening of the externus of the cataphoric eye, whatever hyperphoria alone may exist should be treated, if suffi-

ciently great in quantity, by a central partial tenotomy of the superior rectus of the hyperphoric eye; but if the remaining hyperphoria should be complicated with a remaining plus cyclophoria, the inner, and as much as necessary of the central, fibers of the superior rectus of the hyperphoric eye should be cut.

The operation for sthenic exophoria, uncomplicated, is a central partial tenotomy of one or both externi, preferably both. The object in view being only the alteration of tension, care must be exercised that the plane of rotation shall not be changed.

When sthenic exophoria is complicated by a hyperphoria, the operation on the externi must not be done with a view of affecting the hyperphoria, hence central partial tenotomies are indicated. Later the hyperphoria must be relieved by a central partial tenotomy of the superior rectus of the hyperphoric eye and, if necessary, a central partial tenotomy of the inferior rectus of the cataphoric eye. The tension of these muscles should be altered without a change of plane.

In sthenic exophoria, complicated by a right hyperphoria and a plus cyclophoria, the first operation should be done on the externus of the hyperphoric eye, and it should consist of a division of the upper and central fibers, leaving uncut the lower fibers. The threefold result of this operation will be: (1) relaxing the tension of

the externus, lessening, if not curing, the exophoria; (2) a turning of the eye down, thus counteracting the hyperphoria; (3) torting the eye in, curing the cyclophoria. If some of the exophoria remain, whether still complicated or not by a right hyperphoria and a plus cyclophoria, the operation on the left externus must be a central partial tenotomy. The reason is clear: a division of the upper and central fibers would so change the muscle plane as to increase the cataphoria, although diminishing the cyclophoria; while a cutting of the lower and central fibers would so change the plane as to lessen the cataphoria, but increase the plus cyclophoria. The only safe course between this Scylla and Charybdis is a central partial tenotomy of the left externus. These two operations having been done, any remaining right hyperphoria, without a plus cyclophoria, should be relieved by a central partial tenotomy of the right superior rectus; but if the remaining hyperphoria should be complicated with plus cyclophoria, the nasal and central fibers should be cut, with the double purpose of altering the tension for the hyperphoria and changing the plane for the cyclophoria.

When sthenic exophoria is complicated by a plus cyclophoria only, the upper and central fibers of both externi (not one alone) should be cut. The triple effect of these operations is: (1) alteration of tension for the exo-

phoria; (2) lowering plane of both externi for the plus cyclophoria; (3) the development of a double cataphoria, which, in itself, is not bad.

In asthenic exophoria, uncomplicated, the tension of the interni must be increased by shortenings or advancements so done as not to change the plane of rotation. The same is true of asthenic exophoria complicated by a hyperphoria alone. Later the hyperphoria may be relieved by a central partial tenotomy of the superior rectus of the hyperphoric eye.

When an asthenic exophoria is complicated with a right hyperphoria and a plus cyclophoria, the internus of the cataphoric eye should be so shortened or advanced as to alter its tension, for the exophoria, and elevate its plane, for counteracting the cataphoria and curing the plus cyclophoria. If the internus of the once hyperphoric eye must be shortened or advanced to still further correct the exophoria, not any longer complicated, it must be so done as not to change its plane; and the same is true if the only remaining complication is a hyperphoria, for in counteracting the hyperphoria, a plus cyclophoria would be developed. It is also true that only the tension of the internus should be altered by a shortening or advancement when the remaining exophoria is complicated by hyperphoria and plus cyclophoria, for the reason that lowering the plane would increase

the cyclophoria, although lessening the hyperphoria; while elevating the plane would increase the hyperphoria, although diminishing the cyclophoria. Later the hyperphoria or hyper-cyclophoria should be remedied by the correct operation on the superior rectus.

An asthenic exophoria complicated by a plus cyclophoria must be treated by such shortening or advancement of both interni as to alter the tension for the exophoria and elevate both planes for the plus cyclophoria. The double hyperphoria resulting would be counteracted by a pose of the head.

Cyclophoria may exist alone and may be so high in degree as to demand relief by operation. This can be accomplished by operating on both superior or both inferior recti. A plus cyclophoria, uncomplicated, can be relieved by dividing a few of the nasal fibers or advancing a few of the temporal fibers of both superior recti. In doing the former a double cataphoria is developed, while the cyclophoria is cured; in doing the latter the cyclophoria is cured, but a double hyperphoria results. Since a double cataphoria is preferable to a double hyperphoria, a division of the nasal fibers of the superior recti should always be chosen.

The plus cyclophoria can be cured by a division of the temporal fibers or an advancement of the nasal fibers of both inferior recti. The former would give a double

hyperphoria, while the latter would give a double cataphoria; hence, of the two the latter should be chosen. As to final results, a division of the nasal fibers of the superior recti and an advancement of the nasal fibers of the inferior recti are precisely alike; but the former should be preferred, for it is more easily done and gives the patient much less inconvenience.

Operations on the Recti.

The strictest antiseptic precautions must be observed in the preparation of the patient and the instruments; and the operator and assistant must have clean, asep-

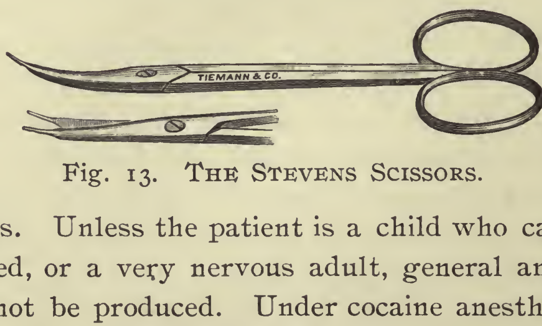

Fig. 13. The Stevens Scissors.

tic hands. Unless the patient is a child who cannot be controlled, or a very nervous adult, general anesthesia should not be produced. Under cocaine anesthesia, the

Fig. 14. The Stevens Forceps.

solution always being made fresh and sterile for each case, muscle operations are practically painless. These

operations may be made almost bloodless by the use of two or three drops of adrenaline chloride solution (1-1000) dropped into the eye while cocainization is being effected in the usual way—one drop of a 10 per cent solution at

Fig. 15. THE STEVENS FORCEPS.

intervals of two minutes, until three or four drops have been instilled. In five minutes after the instillation of the last drop of cocaine solution the operation should be commenced. The stop-speculum, fixation forceps, Ste-

Fig. 16. THE STEVENS HOOK.

vens scissors, and Stevens hook constitute the array of instruments necessary for doing partial tenotomies. If a muscle is to be advanced, a needle holder, two small needles curved at the point, number five silk (either white

Fig. 17. THE STEVENS NEEDLE HOLDER.

or iron dyed), a large strabismus hook, and a silver suture plate must be added to the instruments named; and if a shortening operation is to be done, an additional large strabismus hook, or, probably what would be bet-

ter, the muscle forceps devised by Clark, of Columbus, O. Most of these instruments are shown in accompanying cuts. The time occupied in doing any of these operations is short. The after treatment consists in using freely, several times a day, while the redness lasts, an anodyne-antiseptic wash (Tinct. Opii, gtt. xv, Acid Boracic, gr. xv, Dist. water, oz. i). Both eyes should be kept open, to favor easier binocular adjustment. A muscle suture should be removed on the fifth day, unless severe reaction should indicate an earlier removal. The Price silver suture plate does its best work in facilitating the removal of the suture, making this step painless as well as easy. It prevents the swollen tissue from concealing the knot.

Partial Tenotomy.

There are two kinds of partial tenotomy, central and marginal. The indications for the one or the other may always be well understood in any given case, as has been set forth in another part of this chapter. The object of the central tenotomy is only to lessen the tension of the muscle; the object of the marginal tenotomy is both to lessen the tension of the muscle and to change its plane of action.

To do a central partial tenotomy, the lids must be well separated by the speculum. The patient must look

as far as possible in the direction opposite the muscle to be operated upon. The conjunctiva over the insertion of the tendon must be lifted in a meridional fold with the forceps, and this must be snipped with the scissors. Through the cut in the conjunctiva the forceps should be made to grasp the capsule of Tenon, which in turn should be snipped. Through the openings in conjunctiva and capsule, the central fibers of the tendon should be grasped with the forceps and slightly raised from the sclera, so that they may be cut with the scissors between the forceps and the attachment, as close to the latter as possible. Thus the tendon is buttonholed. If the operator is certain, from the resistance he feels with the forceps, that he is not too near either margin of the tendon, he may divide a few more fibers, in both directions, while still holding the tendon with the forceps; but in doing so he takes some risk of doing too much. Now the forceps should be laid down for the small hook, which should be passed through the buttonhole in the tendon, first in one direction, then in the other, beneath the uncut fibers, so as to determine the resistance. Guided by the hook, the operator now divides fiber after fiber with the scissors, until the lessened resistance warns him that he has gone far enough in that direction. He then repeats this step toward the other margin in the same careful way. Some of the fibers in both directions

must be left uncut, so as to act as stay cords to prevent a too far recession of the cut part of the tendon. The strength of the uncut fibers at the margin should be left as nearly equal as possible, so that the muscle plane may be the same after as before the operation. Should the fibers be left stronger at the one margin than at the other, the plane will be certainly shifted toward the stronger fibers, and an undesired torsioning effect will accompany the lessening of the tension. To get the full effect of a partial tenotomy, the capsule of Tenon must be cut coextensively with the division of the tendon. The cut in the conjunctiva may or may not be of the same extent. There is no necessity for making either a very small or a very large conjunctival incision; but for those just beginning to operate, a large conjunctival incision would make the tenotomy both easier and safer.

Dr. George H. Price, of Nashville, has just invented an instrument that may prove to be most useful, in that it can measure the amount of resistance of uncut fibers when a partial tenotomy is being done. Up to the present, operators have been guided only by an indefinable sense of resistance when drawing on the hook. If that resistance can be measured—and the tendonometer gives promise in that direction—eventually a rule of practice may be established which will be valuable to any operator, whether experienced or inexperienced. Fig. 18 will

give the reader a fair understanding as to the construction of the instrument; however, a description by the inventor follows:

The Tendonometer.

"This instrument, as its name implies, is designed for measuring the resistance of the ocular muscles, either in part or as a whole. It consists of a muscle hook (a), with graduated shaft (s), which is suspended by a coil spring (c) in a hollow metal handle (h), the construction being upon the same general principle as an ordinary spring balance. The hook proper is 5-16 of an inch long and nearly straight, so that it can be passed under the

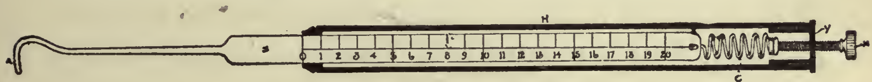

Fig. 18. The Tendonometer.

tendon when it is exposed, and its resistance tested; or it can be passed into the buttonhole made in the tendon when doing a partial tenotomy, and the remaining fibers can be tested, both those above and below the opening in the tendon. The shank of the hook is about 1 1-2 inches long, and round. The shaft of the hook (s) is about 3 1-2 inches long, 1-16 of an inch thick, and 3-16 of an inch wide. The shaft is graduated on both sides, as indicated in the diagram. At its upper end there is a

small eyelet into which the spring is caught, by which it is suspended from the screw (x), which passes through the cap (y), which fits into the upper end of the handle (h). The spring is made of some material such as nickel plated steel, hardened gold, or bronze, to prevent rusting. The handle is made of aluminium. It is rectangular in cross section, being about 3-16 of an inch x 1-4 of an inch, slightly roughened to prevent slipping in the fingers of the operator. At (x) the body of the handle is thickened, and its end is slotted with an opening just large enough to admit the shaft of the hook, or it can be provided with a cap which is slotted and slips into the handle, the cap being made of harder metal. The cap (y) at the upper end of the handle is made of hard metal, is drilled and tapped, so that the screw (x) passes through this and can be screwed in or out to adjust the tension on the spring (c), so as to keep the zero mark of the scale fixed. The screw (x) will be provided with a small jam nut, not shown in the cut, so that when the spring is set this nut can be jammed down against the cap (y) and prevent displacement of the spring and shaft. The graduations upon the shaft of the hook will measure the units of resistance of a tendon or part of a tendon; and the instrument is designed for the purpose of aiding in the accurate performance of those operations which require a very delicate sense of touch on the part of the

operator, something very hard to acquire and not governed by any fixed standard."

A skilled operator can easily grasp conjunctiva, capsule, and tendon at the same time, and go through them all with one snip of the scissors. He then completes the operation as already described.

If the indication is for a marginal tenotomy, the initial cut of the conjunctiva, capsule, and tendon is made as for a central tenotomy, care being exercised that the button-hole in the tendon, if not in the center, shall be nearer that margin which is to be completely severed later. Still holding the tendon with the forceps, the scissors may be passed in the direction in which complete division is indicated, and be made to cut all the fibers at once. The hook should now be used—first, to determine that all the tendon has been cut toward the one margin; and next, to test the resistance of the uncut fibers at the other margin. If this resistance is too great—it would be unfortunate if it were too little—other fibers may be divided. But a sufficient number of fibers at this margin should be left intact to prevent an over-effect. This operation must not only lessen the tension of the muscle so as to favor its direct antagonist, but it must also change the plane of its action so as to cure a complicating cyclophoria.

There is no mathematical rule by which to be guided

in these operations. The beginner should always aim at accomplishing *less* than the effect desired, while the expert operator should be careful not to do *too much.* In these operations, as in all others, practice alone can give the greatest skill and the highest degree of accuracy.

Muscle Shortening.

This operation,* rather than advancement, should be done in nearly all cases of heterophoria, in which the indication is to increase the tension of the muscle. Not only can this operation alter the tension of the muscle, but it can also be done so as, at the same time, to change its plane of rotation. Its advantages over the advancement operation are three: First, it is easier of accomplishment, though a little more painful; second, its plane of rotation is less likely to be changed when there is no indication for changing it; third, the stitch is not so likely to cut its way out, and if it does so, or if the knot should become untied, the case would be no worse than before the operation; whereas, if either of these accidents should happen to an advancement, before adhesion has formed, the recession of the muscle might be farther back than its original attachment. However, in some cases of heterophoria, in which the indication is to in-

* See Ophthalmic Record, March, 1893, in which it was first described.

crease the tension, the muscle attachment is so far back, or the muscle itself is so small, that an advancement must be done.

The shortening operation for simply increasing the tension of the muscles is done as follows: Lids must be widely separated with the speculum. The conjunctiva must be seized with the forceps, so as to be thrown into a fold parallel with the corneal margin, behind the tendon insertion; and this conjunctival fold, if the muscle be an externus or an internus, must be cut with the scissors a little below the lower border of the muscle; but if it be a superior or inferior rectus, the cut must be to the nasal side of the muscle. Through this cut the capsule of Tenon is grasped and cut in line (meridionally) with the conjunctival cut. Through the opening thus made, one of the large strabismus hooks is passed beneath the muscle and drawn forward until stopped by the attachment of the tendon; then, through the same opening, the second large hook is passed beneath the belly of the muscle and carried backward, at the same time lifting the muscle from the sclera, so as to show the extent of the possible shortening. If the opening in the conjunctiva and capsule, by being too small, should stop the second hook too soon, it should be enlarged toward the equator by a cut or two of the scissors. Having already armed the number five silk with two needles, the operator

places one of them in the needle holder, and, passing it through the cut beneath the muscle, forces it through the upper border of the tendon, close to the sclera (if an internus or an externus, but the outer border if a superior or inferior rectus), and brings it out at once through the capsule and conjunctiva. While doing this the tendon is held up by the first hook and the needle is passed between this hook and the sclera. No other puncture will have to be made with this needle, but it should remain on the suture so as to facilitate the passing of that end of the suture through one of the holes of the suture plate later. The first hook remaining under the tendon and still held by the operator, the assistant is directed to pass the other hook as far back beneath the muscle as possible, at the same time lifting the muscle well from the sclera. The operator, with the second needle in the holder, passes it through the opening beneath the belly of the muscle as far back as he wishes, when he forces it through the muscle, then through the capsule and conjunctiva, so that a line connecting this and the first puncture shall be parallel with the plane of rotation of this muscle. The suture is now drawn on so as to make the thread disappear beneath the muscle. The second needle is again placed in the holder, and the operator passes it through the conjunctiva, capsule, and the other border of the muscle, bringing it out through the cut in the con-

junctiva and capsule. The third puncture is so made that the loop of thread passing from the point of the second puncture to it, and lying on the conjunctiva, shall be parallel with the equator of the eye. Now the assistant's hook may be removed. The surgeon again places the second needle in the holder and passes it through the cut beneath the tendon, which he still lifts with his own hook, and forces it through the other border of the tendon close to its insertion, and brings it out through capsule and conjunctiva, so that a line connecting the first puncture and this, the fourth, shall be parallel with the corneal margin, and the line from the third to the fourth puncture shall be parallel with the plane of rotation. Drawing on this end of the suture, that part of it between the third and fourth punctures disappears beneath the muscle. The operator's hook is now removed, and the two needles, after being made to carry the two ends of the suture through the holes in the silver plate, are also removed. It only remains to tie a surgeon's knot over the plate, drawing sufficiently hard to bring forward that portion of the muscle lying beneath the loop which rests on the conjunctiva, until it rests in contact with the tendon at its insertion. The knuckle of muscle, capsule, and conjunctiva thus made demands no attention, since, in the course of a few weeks, it disappears by absorption atrophy. The patient will complain some at the

first two passages of the second needle, and also of the drawing brought about by tying the knot. The after-treatment is the same as that for partial tenotomies.

If a shortening is to be done so as not only to alter the tension of the muscle, but also to change its plane of rotation, the operation differs from that already described only in the making of the four punctures while placing the suture. Let the condition to be relieved be an asthenic exophoria complicated by a plus cyclophoria, in shortening an internus it should be that one belonging to the cataphoric eye, provided there is a vertical error, otherwise both interni should be shortened. The first needle should be passed as nearly as possible through the upper border of the tendon; the second needle should make its first puncture through the muscle below the plane bisecting it, while its second puncture should be made as near as possible to its lower border. The third puncture with the second needle should be made between the first puncture and the plane bisecting the attachment of the tendon. Thus it will be seen that the first and fourth punctures are above the natural plane of rotation, while the second and third punctures are below this plane. In tying the knot, the lower border of the muscle is carried upward, and in this way the muscle is given a new and higher attachment, and thereby the plane of rotation is correspondingly elevated.

If the external rectus must be shortened to cure an asthenic esophoria complicated by a plus cyclophoria, the position of the punctures should be reversed; for in such a case the plane of rotation must be depressed by the creation of a lower attachment, and both externi must be thus operated upon. If there is also a hyperphoria, this operation should be done only on the externus belonging to the hyperphoric eye.

If the superior rectus is to be shortened to cure an asthenic cata-cyclophoria of the eye to which it belongs, the first and fourth punctures must be to the outer side of its old plane of rotation, while the second and third punctures should be on the inner side of this plane. Tying the knot will create a new attachment farther toward the temple than the original one. Thus the plane of rotation is shifted out. Just the reverse must be true of the punctures if they are to be made on the inferior rectus with the view of curing an asthenic hyper-cyclophoria of the eye to which it belongs. This would shift its point of attachment toward the nose, carrying the plane of rotation with it.

Partial marginal shortenings may be done for the relief of cyclophoria when there is no special indication for altering the tension of the whole muscle. In such an operation, all the needle punctures should be made on the same side of the muscle plane. To illustrate: There

being but little exophoria, the existing plus cyclophoria may be cured by changing the plane of both interni without greatly increasing the tension of these muscles. For the accomplishment of this the conjunctival and capsular cut must be at the upper border of the muscle; the needles must be passed the four times entirely in the upper half of the muscle and tendon; and the space between the insertion of the tendon and the loop of the suture must not be anything like so great as in a shortening of the whole muscle. Tying the knot over the suture plate folds only the upper part of the muscle, the power of this part being thereby increased. The same operation should be done on the internus of the fellow eye.

If the partial marginal shortening, to cure a plus cyclophoria, is to be done on the externi, the lower margin of the muscle and tendon is the part to be folded, and the effect should be divided between the two externi. If, for the same condition, the operations are to be done on the superior recti, the suture must be taken in the temporal margin of each; if on the inferior recti, the inner margins only must be folded. But better and easier than partial marginal shortenings would be marginal advancements.

Advancement Operation.

While the necessity for this operation exists only rarely in cases of heterophoria, yet it must now and then be

done. If there is no complicating cyclophoria, the advancement must be made directly forward, so that after the operation the plane of rotation shall be the same as before. The same careful preparation of patient, instruments, and hands must be made as for shortening; and the same instruments are needed, except that only one hook will be required. This operation, done under cocaine, is less painful than a shortening, and is about as quickly done. The lids should be separated widely with a speculum. The conjunctiva should be grasped in line with the center of attachment of the tendon, halfway between the attachment and the margin of the cornea, and in such a way as to lift a meridional fold, which should be cut with the scissors. This cut, after gaping, should be about as large as the tendon insertion is wide. The posterior flap should be drawn backward to a point just behind the insertion. Now, by means of forceps and scissors, a snip should be made through the capsule at one border of the tendon, and through the opening thus made a large hook should be passed beneath the tendon. While the assistant holds the conjunctival flap back, the operator raises the tendon with his hook, and then passes one of the two needles with which the suture is armed, twice through the capsule and tendon, so as to include its center, and a little way behind its insertion. This is done in the manner of taking a stitch in cloth.

The assistant now takes hold of the two ends of the suture and draws the loop well up against the under surface of the tendon, at the same time lifting the tendon slightly away from the sclera. Aided by the hook, the operator now completely divides the tendon, at its insertion, with one or two snips of the scissors. The next step is to make a pouch beneath the anterior conjunctival flap, which is easily done with forceps to hold and scissors to cut. This pouch should be made directly in front of the old attachment, and neither higher nor lower, if the muscle is an externus or an internus, nor farther out or in, if the muscle is a superior or inferior rectus. In either case, the pouch should extend up to the corneal margin. The next step is to pass the two needles through the posterior conjunctival flap a little way behind its edge. Now the operator lifts the anterior conjunctival flap with the forceps and carefully passes one needle, held by the needle holder, into the pouch already prepared, and makes it dip well into the sclera, but not through it, a little above (if it be the upper needle) an imaginary line bisecting the original attachment, and only the slightest distance away from the cornea. In passing out of the sclera the needle penetrates the conjunctiva. This needle is now held out of the way by the assistant, while the operator passes the second needle in the same way, but a little below the line bisecting the

original insertion. The needles are now passed through the holes in the silver plate, after which they are removed. The assistant now grasps the conjunctiva, capsule, and muscle just behind the loop and forcibly draws these structures well forward, while the operator ties the knot. The farther the loop of the suture is passed through the tendon behind the insertion, the greater will be the effect of the operation. The suture passed, as described above, the tension of the muscle will be increased, but its plane of rotation will not be changed.

Since a suture thus taken is not likely to cut its way out, even to a small extent, too much over-effect should not be attempted. If the needles were not made to dip into the sclera, but simply passed through the conjunctiva near the corneal margin, an over-effect would be necessary, for the reason that the thread will partly cut its way out before adhesion has formed, allowing some recession of the advanced tendon. There is even danger that the thread will cut its way entirely out if passed only through the conjunctiva, when, of course, the recession would be excessive. No advancement operation is safe unless the suture is well anchored in the sclera.

An advancement intended not only to alter the tension, but also to change its plane of rotation, differs from the operation thus described only in selecting the place for the sclero-conjunctival stitches. If the muscle to be

thus operated upon is an internus, and the exophoria is complicated by a left hyper-cyclophoria, the one to be advanced is the right internus, when one of the objects in view is the elevation of its plane of rotation. The tendon must be found, and a loop of the suture must be passed through it, as for a straight-forward advancement. After completely severing the tendon from the attachment, the conjunctival pouch must be made higher than the original attachment. The two needles must now be passed into the pouch, and made to dip into the sclera, then out through the conjunctiva, at chosen points, higher up than the old attachment, and close to the corneal margin. On tying the suture thus passed, the muscle is carried higher up on the globe, as well as farther forward. Thus its tension is altered so as to cure the exophoria, and its plane is changed so as to counteract the cataphoria and the plus cyclophoria.

In like manner the plane of either the externus or the superior or inferior recti may be changed by an advancement, the only difference being, in cases of plus cyclophoria complicating other phorias, the direction in which the plane is to be shifted. That of the externus must be carried lower; that of the superior rectus, farther out; that of the inferior rectus, farther in.

Marginal advancements may be done on both interni when there is only a slight asthenic exophoria complicated

by a plus cyclophoria. In doing this, the stitch in the tendon should be in its upper border; only the upper fibers should be cut at the insertion, after which, by means of scleral stitches, this part alone should be brought straight forward, or only slightly higher, and not very far in advance of the old insertion.

Similar operations on the externi, or on the superior and inferior recti, may be done under proper indications, the operator being certain that he has selected the proper part of the tendon for the partial advancement.

In all advancement operations the suture should be tied over the silver plate, and should be allowed to remain in place five days, so as to give enough time for the formation of adhesions. In removing the suture, care should be exercised that the adhesions may not be torn loose.

The after-treatment should be the same as for partial tenotomies; that is, the free and frequent use of the antiseptic-anodyne solution.

Other methods of making the advancement operation might be given. The main objection to the high-and-low stitch operations, devised and advocated by Beard, of Chicago, and Black, of Denver, is that the advanced tendon cannot be accurately placed, so that in one case the plane of rotation may be changed, when it should have remained as before; while in another case it might

remain as before, when it should have been changed. Nor are these operations so simple or so free from traumatism as the very easy and safe method indorsed and advised in this chapter.

Again, let it be said, advancements are rarely indicated in the treatment of heterophorias, and, whenever possible, should be substituted by the operation of shortening, which is easier, safer, and better. But in heterotropias, as will be shown in Chapter IX., advancements are indicated in . .arge proportion of cases.

CHAPTER IV.

ESOPHORIA.

THERE is an esophoria which, because of its nature, may be called "true," or "intrinsic;" while there is another form that should be termed "pseudo." The one kind is entirely distinct from the other, and yet the two often co-exist, the one being grafted on to the other. Whatever may be the kind of esophoria, there is a tendency on the part of the interni alone, or with the aid of their synergists, to converge the visual axes at a point between the observer and the object fixed; but this too near intersection of the visual axes is prevented by excessive nerve impulses sent to the antagonizing muscles, increasing their tension abnormally. In the interest of binocular single vision the too great inherent tension of the interni is counteracted by a corresponding nervous tension of the externi.

INTRINSIC ESOPHORIA.—In this condition the interni have an advantage over the externi, which may be due to any one of several conditions. It may be that the interni are over-developed, or, what would result in the same thing, the externi may be under-developed. In

either case there would be an imbalance in favor of the interni. That this is often true hardly admits of a doubt; for every surgeon who has operated often will testify that, in operating on the internus to lessen its tension, he has frequently found it very large and strong, and that, in operating on the externus to increase its tension, he has found it small and weak.

The interni may not be over-developed, but abnormally short; or the externi may be abnormally long, thus giving an imbalance in favor of the interni. In operating on an internus to lessen its tension, it is sometimes found to be tense, as if stretched; while in operating on an externus to increase its tension, this muscle is found loose and flabby.

The interni may not be over-developed nor the externi under-developed, nor may the interni be too tense while the externi are too lax. The esophoria found in such a case would be due to the interni having their attachments too far forward, while the externi have their attachments too far removed from the corneal margin.

If either of the conditions mentioned above should be the cause of an esophoria, it can be understood readily how the esophoria may be greater in the one eye than in the other, and that it may exist only in one eye, the lateral muscles of the other eye being perfectly balanced. This can be determined quickly and accurately by means

of the monocular phorometer, the binocular phorometer being wholly unreliable for this purpose.

Whatever may be the cause, esophoria is usually about equal in the two eyes. Regardless of the existence of the one or the other of the four causes discussed, or that two or more of them may coexist, the treatment, as will be shown, must be directed either toward the interni with the view of lessening their tension by partial tenotomies, or toward the externi with the view of increasing their power by means of exercise or by shortening or advancing one or both of them. In low degrees of the error, prisms in positions of rest for the weak externi may be tried.

True, or intrinsic, esophoria may not depend on either one of the four causes mentioned, but may be caused by a naturally over-developed third conjugate innervation center which, without being over-stimulated, continually, during waking hours, is sending excessive nerve impulses to the otherwise normal interni, to counteract which, over-stimulation of the centers controlling the externi is demanded; or there may be an under-development of the centers controlling the externi, requiring that these shall be over-stimulated in order that a nerve impulse sufficiently strong shall be sent to the externi to counteract the normal impulse sent to the interni. The third conjugate innervation center is wholly undeveloped

in some cases, there being entire absence of power to converge; in other cases it appears that this center is not fully developed; hence it is reasonable to conclude that now and then an over-development of this center exists. If so, the esophoria is as true, or intrinsic, as if the muscles themselves were at fault. There may be, or there may not be, a conjugate innervation center for the externi; but, if so, it is only intended that it shall force the externi to counteract the tendency on the part of the interni to make the visual axes cross too soon. It would not be in the interest of binocular single vision for a conjugate divergence brain center to exist, hence the supposition that there is no such center.

Unless one or more of the above-mentioned causes exists, there can be no such thing as an intrinsic esophoria. The superior and inferior recti, when attached, in greater part, on the nasal side of the vertical meridian of the eye, act as a secondary cause of true esophoria.

Malformation of the orbits cannot have much to do, directly, with the causation of intrinsic or even pseudo-esophoria. As has been shown in Chapter I., the angle of convergence for eyes that are wide apart is but little greater than the angle of convergence when the eyes are close together, and yet that little may constitute one of the factors in the production of an esophoria, or, *vice versa*, of an exophoria. When the eyes are 3

inches apart and the point of fixation is 16 inches, the angle of convergence is 10.7°, while the angle of convergence for the same point, the eyes being 2 inches apart, would be 7.16°, a difference of 3.54°. It is, therefore, reasonable to conclude that a muscle adjustment that would give orthophoria when the eyes are 3 inches apart would give esophoria if they were only 2 inches apart. It is also reasonable to conclude that a muscle adjustment that would give orthophoria, the base-line being 2 inches, would give exophoria if the base-line were 3 inches. Malformation of the orbit must play only a very small part in the production of an esophoria or an exophoria.

STHENIC ESOPHORIA.—The quantity of the esophoria does not determine its character with any certainty. If the error is sthenic in character, it can be told only by resorting to the duction and version tests. How to make these tests has been fully set forth in Chapter II. and Chapter III.; and so important are these tests, from a therapeutic standpoint, they can never be safely neglected. In sthenic esophoria adduction should be more than 25°, and adversion should be more than 50°. Abduction and abversion may be only little less than normal, and rarely would these exceed the normal. More dependence must be placed on abduction and abversion than on adduction and adversion in determining

if an esophoria is sthenic. If, in a case of esophoria, abduction and abversion are nearly normal, it is of the sthenic type.

ASTHENIC ESOPHORIA.—Here, again, it is not the quantity of the error that determines its character. It is only by the duction and version tests that the asthenic may be distinguished from the sthenic. In such a case the adduction power is less than 25°, and the adversion is less than 50°. Abduction and abversion will be correspondingly low. If in responding to these tests a patient should show less duction and version power than he really has, the error will be on the safe side. In asthenic esophoria the interni should never be operated upon. What to do for such cases will be fully set forth under the head "Treatment."

PSEUDO-ESOPHORIA.—As its name implies, it is an esophoria that has neither of the above-mentioned causes. It is wholly dependent on the relationship that exists between the third conjugate innervation center and the center controlling the ciliary muscles. It is never found in a myope; it is never shown in the distant test when the patient is an emmetrope. Even an emmetrope may show a pseudo-esophoria in the near, but only when the ciliary muscles are weak and must receive an abnormal impulse in order to focus near objects. Pseudo-esophoria always exists in cases of hyperopia,

manifesting itself in one of three ways: first, lessening the quantity of an intrinsic exophoria; second, showing an esophoria when, in reality, there is no imbalance between the lateral recti; third, showing a greater quantity of esophoria than really exists. Though false in character, it is nevertheless harmful, unless it complicates an exophoria. Then, as will be shown in the chapter on exophoria, it is helpful in the absence of any treatment of the exophoria.

Donders was right when he emphasized the influence that accommodation has over convergence, though some have doubted that there is any truth in his teaching on this subject. He may have attached too much importance to it; doubtless he did go beyond bounds when he taught that hyperopia was the chief cause of internal strabismus. Some idea of the probable effect that accommodation has over convergence may be obtained by the study of eyes that are emmetropic and orthophoric. Such eyes accommodate 3 D for a distance of 13 inches. The distance between the centers of the eyes being $2\frac{1}{2}$ inches, the angle of convergence for 13 inches will be 11°. Each eye accommodates 3 D, and its visual axis is turned toward the median plane of the head through an arc of 5.5°, showing nearly 2° of convergence for 1 D of accommodation as the normal. This holds almost true when the accommodation is 1 D, the point of fixation be-

ing at a distance of 1 M. The base-line being $2\frac{1}{2}$ inches, the angle of convergence will be 3.6°, half of which (1.8°) will show the converging of each axis toward the extended median plane of the head. To show how nearly the proportion holds good, the following is given: 3 D: 5.5° :: 1 D: 1.8°. Thus it would appear that 1 D of hyperopia would give 1.8° of pseudo-esophoria, the proportion practically holding good up to 6 D, there being a variation of only .1°. In 6 D of hyperopia the pseudo-esophoria for each dioptre would be 1.9°.

A pseudo-esophoria may be chargeable, in some unaccountable way, to a complicating plus cyclophoria. This surmise becomes stronger since it is well known that an esotropia occasionally has for one of its causative factors a plus cyclophoria, which must be corrected to make it possible for the esotropia to be cured. There must be, however, an intrinsic esophoria, which is only aggravated by the cyclophoria.

In many cases of esophoria the distant test shows a greater error than the test in the near, and in some cases an esophoria is shown in the distant test and an exophoria in the near. Occasionally the esophoria shown in the near test is from 1° to 10° greater than that shown in the far test. This variation will not show itself when the esophoria is wholly intrinsic. If there is emmetropia, the esophoria in the distant test is intrinsic,

and the same quantity of the error will be shown in the near test, if the ciliary muscles are ideal in structure and size and ready to give full response to the normal stimulus sent to them from the brain-center that controls their action, when accommodating for the near point. If the point to be fixed is 16 inches from the eyes, the impulse sent from the brain to the ciliary muscles will be a 2.50 D impulse and the muscles will respond so as to increase the refraction of the lenses 2.50 D. The associated impulse sent to the interni, the distance between the eyes being $2\frac{1}{2}$ inches, would be enough to make the two visual axes swing toward each other 4.5°, so that the angle of convergence would be 9° (a small fraction less). If the diplopia test in the distance shows 6° of esophoria, the near test will show the same, for nothing exists to break the evenness of the error. In another case of emmetropia, suppose the ciliary muscles to be subnormal in their development, so that more than a 2.50 D impulse must be sent from the brain-center in order to make them respond sufficiently to increase the refraction of the lenses 2.50 D. For the sake of argument, let a nerve impulse of 5 D be necessary to elicit a 2.50 D response on the part of the ciliary muscles; the associated impulse sent to each internus would be double that of the normal ($4.5° \times 2 = 9°$) in the effort to accommodate at 16 inches. The distant

test showing 6° of esophoria, the near test would show 10.5° of esophoria (6° intrinsic esophoria + 4.5° pseudo-esophoria = 10.5°).

In another case of emmetropia, suppose the ciliary muscles to be hyper-developed, so that only a 1.25 D nerve impulse is necessary to elicit a 2.50 D response by the ciliary muscles; the associated impulse sent to the interni would be just half the normal (4.50° ÷ 2 = 2.25°) when accommodating for a point at 16 inches. The deficiency of associated impulse must be supplied by a corresponding amount of the inherent tension of the interni, diminishing the esophoria in the near test just to that extent. To the convergence impulse (2.25°) must be added 2.25° of the esophoria in order to have the visual axes form an angle of convergence of 9°. Then, the distance test showing 6° of esophoria, the near test would show 3.75° of esophoria (6° − 2.25° = 3.75°).

In still another case of emmetropia, there may be an intrinsic esophoria of 2° in the distance. The ciliary muscles may be such as to require only a 1 D impulse to call forth 2.50 D of activity on the part of hyper-developed ciliary muscles, in accommodating for 16 inches. The associated impulse sent to the interni would be only 1.8°, when an impulse of 4.5° is required for convergence at 16 inches. When the whole of the 2° of intrinsic tension of the interni is used in aiding convergence, the

guiding sensation must make a special call on the third innervation center for .7° more of convergence on the part of each internus in order that the proper angle of convergence may be formed (associated impulse 1.8° + 2° intrinsic esophoria + .7° extra impulse from the third conjugate center = 4.5°). The diplopia test in the near withdraws the extra impulse from the third conjugate center and exophoria of .7° is shown.

It is not the response of the ciliary muscles in dioptre changes of the lenses that causes a definite associated contraction of the interni, but it is the greater or smaller impulse, measured in dioptres, generated by the brain - center controlling the ciliary muscles, that develops the associated action of the interni; for every 1 D of ciliary impulse there is 1.8° of convergence impulse.

Experiments and observation do not show that an associated nerve impulse is sent to the ciliary muscles from the center controlling them because of an overstimulation of the third conjugate innervation center. This would be shown in spasm of accommodation—pseudo-myopia—a condition never seen in cases of esophoria, and rarely seen at all, even in a case of exophoria. The condition so often spoken of as spasm of accommodation is not such, but is the temporary continuance of the manifestation of an acquired tonicity of

the ciliary muscles, when one begins the wearing of convex lenses for the correction of hyperopia.

Whatever may be true of other associated brain-centers, it appears that the center of the ciliary muscles and the third conjugate innervation center can have the associated impulse run in only one direction; that is, from the former to the latter.

Tests for Esophoria.

No test for esophoria can be relied on when the eyes are under the influence of a mydriatic. Within an hour, and it may be for a much longer time, after the instillation of a mydriatic, the third conjugate innervation center is excessively stimulated, either directly or indirectly, more likely the latter, so that an esophoria will be shown when there is none; existing esophoria will be increased more or less; and an exophoria will be made to appear less than it really is. All of these statements are certainly true, in both the far and the near tests, if the patient is a hyperope; they are true in the near, if not in the far, if the patient is an emmetrope; they are also true in the near, if not in the far, if the patient is a myope of less than 2.50 or 3 D.

The explanation for this phenomenon, given by the author in 1892, he still believes to be true. This explanation is as follows:

A very peculiar feature of the use of a mydriatic is that at first—probably from one to several hours—a mydriatic, in hypermetropic eyes, will increase the esophoria, will lessen an exophoria or convert it into orthophoria, or even into an esophoria. Until now this has been unexplained. The following explanation must be true: The mydriatic acts on either the endings of the accommodative nerve fibers or on the fibers of the muscle of accommodation, certainly not on the accommodative center, which, therefore, must remain in a state susceptible of excitation by the demands from the guiding sensation. As the muscles of accommodation pass into their forced rest, the retinal images become less sharp in outline, the blurring increasing up to the point of full suspension of accommodation. The guiding sensation calls on the accommodative center for sharper images, and the impulse is sent out, but finds the muscles unresponsive; the call is repeated more eagerly, and a stronger impulse is sent to the sleeping muscles, and still no change is effected in the images; and thus the calls and the responses are kept up for a longer or a shorter time. For every degree of activity thus excited in the accommodative center, there is a corresponding *tendency* to activity generated in the converging center. So long as the calls are made on, and responses are made by, the accommodative center, the center of convergence

stands ready to call into unusual action the interni, which they do the moment the guiding sensation is robbed of its restraining power by the test for heterophoria, when an increased pseudo-esophoria is shown. But finally the guiding sensation ceases its calls, or, from exhaustion, the accommodative center ceases to respond, and now the normal muscular condition is again shown, and will remain manifest, although the mydriatic may be continued. From this observation on the mydriatic as a disturber of the salutary relationship of the centers of accommodation and convergence, we deduce the following conclusion: *All tests for lateral heterophoria are wholly unreliable within the first few hours after eyes have been brought under the influence of a mydriatic.*

Tests.

The exclusion test will always show an outward resetting whenever the card is removed. The resetting may be so slight as not to be detected objectively; but the patient will always be conscious of the apparent movement of the test object toward the opposite side, however slight may be the esophoria.

The red-glass test, by taking the eye slightly off its guard because of the change in the color of the image, will result in diplopia in many cases, the red light ap-

pearing on the side corresponding to the eye before which the red glass is held—homonymous diplopia. It will be distant from the true candle, more or less, depending on the quantity of the error. The diplopia developed by the red glass practically always indicates that an operation should be done, but it does not determine the muscle to be operated upon nor the kind of operation to be done. This can be shown only by the duction and version tests of both the interni and the externi.

The double prism, held with the line of union of the bases horizontal, shows the middle, or true, object displaced toward the corresponding side; or, if the true object be fixed, the upper and lower false object will appear on the side corresponding to the position of the double prism. A prism from the refraction case that places the false and true objects in a vertical line, measures the error, but does not indicate the method of procedure to be adopted for effecting a cure. The duction and version powers must be taken.

If the single prism be correctly held before the eye—that is, the axis vertical and the base up—the resulting diplopia will be homonymous; and the extent of the deviation can be measured by prisms, as when the Maddox double prism is made the means of producing the diplopia. The double prism has the advantage over the single prism, whether they are placed in a trial frame or held

in the hand, in that the examiner can always be certain, with the double prism, that its axis is vertical, when the two resulting images are made to appear the one directly over the other. With the single prism there is no such means of knowing the exact position of the axis, hence the chance for the creeping in of an error that, on the one hand, may show more esophoria, while, on the other hand, it may show less, than really exists. The ease with which this source of error might be eliminated by the double prism was really the thought that led Maddox to invent it. Of the two means for developing diplopia by prisms, independent of the phorometer armed with the spirit level, the double prism is by far the better and more reliable.

The Maddox rod was invented because of a defect in the double prism as first made, and as made even now by some manufacturers. The grinding of both prisms on one piece of glass left a somewhat rounded line of union of the bases, so that not only would the candle blaze be doubled when the base-line passed across the pupil, but a streak of light, formed by the refraction of the rays passing through the rounded line of union, extends more or less completely from the one false light to the other. The streak served a good purpose, in that it led to the invention of the indispensable rod; but since it can no longer serve a good purpose, it should

be eliminated by uniting two separate prisms, base to base.

While there is but one certain, therefore legitimate, use for the Maddox rod—viz., in testing the oblique muscles—it is, nevertheless, frequently used in testing the recti.

When the rod is horizontal before the right eye, the vertical streak of light is seen to the right of the candle

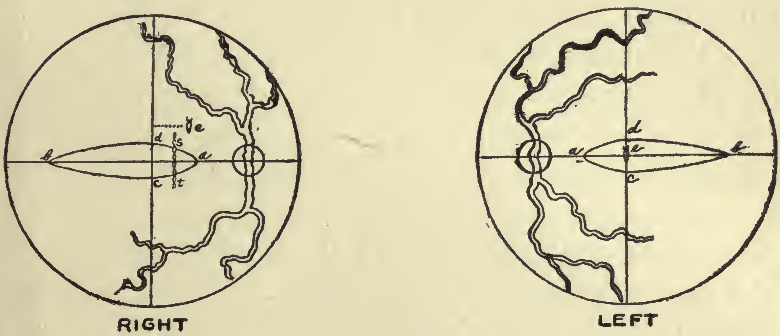

Fig. 19. RETINAL FUSION AREAS.

in every case of esophoria. The prism, base out, that causes the streak to pass down through the light measures, but not accurately, the quantity of the esophoria. The want of accuracy is due to the fact that the vertical retinal meridian is not turned so far out, by contraction of the internus, as to throw the streak entirely outside

the retinal area in which resides the guiding sensation; therefore there would be some effort made at fusing the part of the much-changed image with the true and unchanged image in the other eye. Fig. 19 shows this better than words can possibly portray. The figure also shows how a displacing prism, with base up, would throw the unchanged image of the candle blaze above and entirely beyond the fusion area, so that no effort would be made by the eye to disturb the position of equilibrium into which it has turned. It will be seen also that the rotary prism would carry the displaced image to the vertical meridian without having it infringe anywhere on the fusion area. The dotted line from *e* represents the line of travel of the image while the measurement of the error is being taken with the rotary prism. At no time would a fusion impulse be excited. Not so with the streak of light which crosses the fusion area. The nearer this is carried by a rotary prism, or a simple prism, base out, to the vertical retinal meridian, the greater would be the demand made by the guiding sensation on the center controlling the external rectus. For this reason the rod test will give variable results from time to time, and will always show less esophoria than the patient really has. The same is true even to a greater extent when the rod is used for testing for exophoria and for hyperphoria and cataphoria. There is

only one means for testing for esophoria that is less reliable than the rod, and that is the strong plus lens suggested by Stevens.

From every standpoint the phorometer constitutes the most desirable means for detecting esophoria and measuring it. For reasons given in Chapter II., the monocular phorometer is the best. The displacing prism should always be placed, base up, in the cell toward the patient's eye; the thumbscrew for the rotary prism should be in the horizontal; the index of the rotary prism should stand at zero; and the spirit level should be exactly regulated. The upper, or true, object should be fixed. The six-degree displacing prism will throw the false image above and entirely beyond the retinal area of binocular fusion, taking the guiding sensation of that eye entirely off its guard, so that the eye will at once be turned in. The lower, or false, object will be proportionately displaced from the vertical toward the corresponding side—homonymous diplopia. Revolving the rotary prism so that its index moves in the nasal arc, the false object is brought farther and farther toward the vertical line passing down from the true object, until at last the patient observes that the false object is directly under the true object. The point at which the index stops tells the degree of the error. The same result, practically, will be shown by any number of tests

on the same day or on consecutive days, if the patient is always careful to "fix" the true object. This point is absolutely essential to the greatest accuracy; and if strictly observed, there is no other factor to bring in an error. Certainly at no time will the false image be within the retinal area of binocular fusion.

The one eye tested, the instrument should be reversed so as to test the other eye, for in this way only can it be determined if there is more esophoria in the one eye than in the other.

To know how to proceed in the treatment of any given case, this question must be answered: Is it pseudo-esophoria? This is answered by a study of the refraction under a mydriatic a little later. If there is no hyperopia or hyperopic astigmatism, the answer is: "No." If there is hyperopia or hyperopic astigmatism, the answer is, "Yes, at least in part," which part can be easily calculated, for it would be 1.8°, or nearly 2°, for every dioptre of the hyperopia and as much for every 2 D of hyperopic astigmatism. The quantity of the pseudo-esophoria thus determined, subtracted from the full error, as shown by the phorometer, gives the amount of the true, or intrinsic, esophoria.

But before the mydriatic is used the duction and version power of both interni and both externi should be taken in order that the following two questions may

be answered: Is the intrinsic esophoria sthenic? Is it asthenic?

These three questions answered, the method of procedure becomes plain, as soon as complications have been found or eliminated.

Complications of Esophoria.—These are hyperopia and hyperopic astigmatism, hyperphoria and cataphoria, and plus and minus cyclophoria. The existence or non-existence of one or more of these complications must be known before it becomes possible to resort to the correct treatment of esophoria. It has already been shown how hyperopia and hyperopic astigmatism develop a pseudo-esophoria, which can be cured by proper lenses. A myopia and myopic astigmatism sometimes complicate an esophoria, and when they do, their correction increases the esophoria in the near, but not in the far.

A hyperphoria of one eye and a cataphoria of the other will increase an esophoria, as will also a double hyperphoria and a double cataphoria. How to deal with these complications in the treatment of esophoria will be shown under the head "Treatment."

As already stated, it is difficult to see how a plus or a minus cyclophoria can add to an esophoria, since the oblique muscles are abductors; but it can be seen readily how an esophoria might be lessened by a cyclophoria. It is possible, however, that a cyclophoria may excite

the third conjugate innervation center in some way, so as to develop a spasm of the interni, such as is excited in cases of hyperopia; but there is not that definite relationship between the obliques and the interni that there is between the ciliary muscles and the interni. Nevertheless, when cyclophoria complicates an esophoria, the treatment of the esophoria must include the treatment of the cyclophoria if the best and quickest results are to follow; in fact, it is practically impossible to cure an esophoria while the cyclophoria remains uncorrected.

For the methods of detecting and measuring hyperphoria and cataphoria, and plus and minus cyclophoria, as complications of esophoria, the reader is referred to Chapter VI. and Chapter VII.

Symptoms of Esophoria.

These are any one or several of those mentioned as resulting from heterophoria, and the reader is referred to that part of Chapter III. treating of symptoms; but not all the symptoms resulting from abnormal nervous tension of the ocular muscles are mentioned in that chapter. It would be impossible to make a complete list. There is not a single brain-center controlling any one organ or part of the body that may not be disturbed, in sympathy with the centers that control the ocular muscles; and, *vice versa*, the centers controlling

the ocular muscles may be sympathetically disturbed because of excessive demands on the other centers. The difference between other centers and those controlling the ocular muscles is that the former have not so severe a taskmaster as the guiding sensation which compels obedience, on the part of the ocular muscles, to the law of corresponding retinal points in binocular vision. For this reason no other centers are so likely to be overworked as are the five conjugate innervation-centers whose duty is to control the recti muscles so that the visual axes may always be in the same plane and may be converged at the proper point, and the four conjugate centers that force the obliques to parallel the vertical axes with the median plane of the head. The only exception is the center that controls the action of the ciliary muscles, which must also satisfy the guiding sensation of the retina.

In monocular vision, as when one eye has been lost, the possibility of the excitation of reflex nervous symptoms is greatly lessened. The centers not relieved of the necessity of over-excitation when there is but one eye are the center that sends impulses to the ciliary muscle and the centers that must make the obliques parallel the vertical axis with the median plane of the head. Posing the head in monocular vision would relieve the strain that may have been demanded of the

recti in binocular vision. There is, therefore, truth in the statement that has been made by people who have lost one eye—that "the one eye is stronger than the two ever were."

The symptoms of esophoria are not due directly to the abnormally high inherent tension of the interni, but to the abnormal nervous tension of the externi in their effort to prevent the esophoria from being transformed into an esotropia, or to the nervous tension of other weak muscles in their effort to counteract other errors that may complicate the esophoria.

Treatment of Esophoria.

Errors of refraction that complicate an esophoria should be measured under a mydriatic, and a full correction should be given. If the error is hyperopia, every dioptre of correction will relieve 1.8°, practically 2°, of the esophoria both in the far and in the near; if the error is hyperopic astigmatism, every dioptre of correction will relieve 0.9°, practically 1°, of the esophoria. The pseudo-esophoria is thus cured. Any remaining esophoria is intrinsic in character, unless it be caused by subnormally developed ciliary muscles, which would be shown in the near only.

If the refractive error is myopia, every dioptre of correction will add to the manifest esophoria—in the near,

but not in the far—1.8°, that quantity of pseudo-exophoria which, before correction, served to lessen the esophoria; if the error be myopic astigmatism, every dioptre of correction would add 0.9° to the formerly manifest esophoria, but in the near only. With the correcting lenses on, the esophoria shown by the phorometer is intrinsic in character.

Thus it is shown that the correction of hyperopia and hyperopic astigmatism lessens the nervous tension of the externi by relieving the associated nervous tension of both the interni and the externi; while in intrinsic esophoria the nervous tension is in the externi alone, the tension of the interni being inherent. To obtain full correction of the pseudo-esophoria, the hyperopia and the hyperopic astigmatism should be fully corrected, and the correction must be worn both for near and for far seeing. If the esophoria is wholly pseudo, nothing will be needed but the lenses for effecting a complete cure; but if a part of the esophoria is intrinsic, as may always be known without waiting, other treatment will be necessary sooner or later. The double nervous tension having been relieved by the lenses, all symptoms may vanish for a time; but ultimately the nervous tension of the externi, necessary for correcting the intrinsic esophoria, will cause symptoms to reappear. This marked relief will follow only when the intrinsic

esophoria is low in degree, while the pseudo-esophoria is comparatively high.

The wearing of lenses correcting myopia and myopic astigmatism will cause no change in the muscle imbalance for distance; but in the near, the wearing of the lenses will cause the whole of the esophoria to become manifest, and the nervous tension of the externi will be correspondingly augmented; the symptoms will be aggravated, and the esophoria should receive immediate treatment. Until the esophoria has been cured it will be better to let the patient take the lenses off when engaging in near work, or, at most, wear only a partial correction of the myopic error. Uncorrected myopia lessens the nervous tension of the externi in esophoria by diminishing the normal nervous impulse that would be sent to the interni, if the ciliary muscles were in action.

The effect of focal errors eliminated, the treatment of the intrinsic esophoria depends on the quantity of the error, in so far as non-operative efforts are concerned.

The non-operative treatment of esophoria of low degree is of two kinds—first, prisms in position of action for the stronger muscles or of rest for the weaker muscles; second, exercise of the weaker muscles, which, in cases of esophoria, can be accomplished only by prisms.

Prisms in Positions of Action for the Interni.

Prisms to be worn constantly are always open to the objection that they interfere with the law of direction, but this is sometimes the less of two evils and should be chosen. The visual axis under any and all circumstances points to the apparent source of the light that throws its image on the macula. In obedience to the law of corresponding retinal points, an image that has been displaced, by prismatic action, toward the temporal side of the macula, makes the source of the light appear to be on the opposite side and just as many degrees from its real position as the image has been displaced from the macula. When possible, fusion of the false object with the true object is effected by the internus rotating the eye until the macula is brought under the displaced image. The visual axis points to where the object would appear to be if no attempt at fusion had been made, and of necessity passes through the center of retinal curvature. The visual line that passes from the displaced image to the fused object passes to the outer side of the center of the retinal curve, and is a false line of direction.

Before placing a prism for constant wear by an esophoric, the complicating muscle errors must be considered. The only indication for placing the axis of the prism out of the horizontal is the coexistence of a cyclo-

phoria, usually a plus cyclophoria, either with or without a complicating hyperphoria of the one eye and a cataphoria of the other. If there is no vertical error, but only a plus cyclophoria complicating the esophoria, the prismatic effect should be divided equally between the two eyes, and the nasal end of each axis should be tilted up through a sufficient arc for correcting the greater part of the cyclophoria. This must be determined by testing for the cyclophoria while the prisms are on. The stronger the prisms, the smaller the arc of rotation of the axes; and, *vice versa*, the weaker the prisms, the larger the arc of rotation. To place the prisms, in such a case, with the axes horizontal, would be to leave uncorrected the cyclophoria, a most important factor in the causation of symptoms. To depress the nasal end of the axes of the prisms, in a case of this kind, would be to make the patient worse.

If there is a complicating hyperphoria of one eye and cataphoria of the other eye, as well as a complicating plus cyclophoria, the prismatic effect for the relief of the esophoria should be applied wholly or in greater part to the eye that is hyerphoric and the nasal end of the axis should be elevated. As can be readily seen, a prism thus placed would cause the eye to turn in and up, the direction the strong muscles tend to take it, which rotation would tort the eye in, correcting the plus cyclo-

phoria. If any of the prismatic effect is applied to the cataphoric eye, the axis should be horizontal, for the reason that, while depressing the axis of the prism would rest the weak superior rectus, it would increase the plus cyclophoria; on the other hand, elevating the nasal end of the axis would favor the weak superior oblique, but would add to the abnormal nervous tension of the weak superior rectus.

In a case of esophoria, complicated with a minus cyclophoria, the rule for tilting the axes of the prisms would be reversed all the way through. This complication is exceedingly rare.

If the esophoria is uncomplicated in a given case, the prismatic effect should be equally divided between the two eyes. These prisms can be worn with comfort, provided the two interni are properly attached, and in many cases they can be worn comfortably if the two interni are attached, in greater part, above the horizontal plane of the eyes. In many cases the superior obliques would accept kindly the aid, in paralleling the vertical axes with the median plane of the head, offered by the interni that are attached too high. Constant prisms for esophoria, when uncomfortable, point to attachments of the interni that are, in greater part, below the horizontal plane. In such a case the prisms would have to be abandoned. The combined prismatic

effect, as a rule, should not be more than half the esophoria.

When focal errors require either convex or concave lenses, these can be decentered so as to give the necessary prismatic effect. For esophoria, convex lenses should be decentered out and concave lenses should be decentered in. The same rules for placing prisms should govern the decentering of lenses. It would seem that authors ought to agree as to how much a given lens should be decentered in order to obtain a definite prismatic effect, but they do not. Maddox teaches that a lens of 1 D must be decentered 1.75 cm. (17.5 mm.) to obtain 1° of prismatic effect. He then gives the following formula for determining the extent of decentration of any lens for a required effect: $C = \frac{P \times 1\frac{3}{4}}{D}$, in which C is the centimeters of decentering; P, the desired prismatic effect; and D, the number of dioptres in the lens. Let $P = 1\frac{1}{2}°$ and $D = 3°$, then the formula would be: $C = \frac{1\frac{1}{2} \times 1\frac{3}{4}}{3} = .875$ cm., or 8.75 mm., which is about $\frac{1}{3}$ of an inch of decentering.

Jackson teaches that the following formula is practically correct: $C = \frac{P \times 10}{D}$, in which C is the mm. of decentering required; P, the prismatic effect desired; D, the number of dioptres in the lens to be decentered; while 10 is the mm. of decentering of a 1 D lens for 1° (1 centrad) of effect. Substituting figures for letters, as in the

Maddox formula, we have: $C = \frac{1\frac{1}{2} \times 10}{3} = 5$ mm., or about $\frac{1}{5}$ of an inch of decentering, as compared with Maddox's $\frac{1}{3}$ of an inch of decentering.

Thorington and May agree in taking 8.7 mm. for the extent of decentering a 1 D lens in order to procure 1° of prismatic effect. For obtaining the amount of decentration of any lens, this would be their formula: $C = \frac{P \times 8.7}{D}$. Substituting figures for letters, as in the other formulas, we have: $C = \frac{1\frac{1}{2} \times 8.7}{3} = 4.35$ mm., or about $\frac{1}{6}$ of an inch of decentration, as compared with Maddox's $\frac{1}{3}$ of an inch and Jackson's $\frac{1}{5}$ of an inch; or, comparing in mm.: Maddox, 8.7; Jackson, 5; Thorington, 4.35; May, 4.35. By a little experimentation the reader may satisfy himself that Jackson is practically correct. The extent of decentration advised by Maddox is entirely too much—nearly double what it ought to be. It may be that Maddox's estimate was for 1° of arc, and not for 1° of prism, or 1 centrad.

One advantage that decentering a lens has over the grinding of a lens on a prism is that the former is cheaper; another advantage is that the wearing of a decentered lens is not attended by the reflected image of any bright object, which is always toward the refracting angle and in the line of the axis of the prism, unless the prism is ground on both surfaces. Chromatic aberration is no more, nor is it any less, with a decentered

lens than it is with a lens ground on a prism. The great objection to decentered lenses is that the spherical aberration must interfere to some extent with the sharpness of retinal images; this, however, is but little when the decentering is 6 mm. or less, and rarely is it more. In very strong lenses, say 6 D, the decentering would be only 5 mm. for 3° of effect.

The greatest objection to "relieving prisms" and to decentered lenses is that they favor muscles in their weakness. They lessen nervous tension, but not by increasing the inherent power of weak muscles. It is far better practice to increase the inherent power of weak muscles, either by exercising them or by shortening or advancing them, or to increase the relative power of the weaker muscles by lessening the tension of their stronger antagonists by partial tenotomies. If patients will not resort to exercise and decline to submit to operations, they should be given the benefit which is to be derived from prisms in positions of rest or from decentered lenses.

Exercise Treatment for Esophoria.

Uncomplicated intrinsic esophoria of low degree may be cured by proper exercise of the externi. The only means applicable are prisms. The same gymnastic principles apply to the externi as to the other muscles of the body.

Light work, not continued too long, and rhythmic in character, is exercise that increases muscular power. Prisms of from 1° to 4°, bases in, can be used for developing the externi. Beginning with the weaker prisms and advancing to the next stronger at intervals of a week or ten days, the strongest to be used are soon reached. The exercise should be resorted to at the same time every day, so as to easily form the habit of exercising, and should be continued not longer than ten minutes at a time. One exercise daily—or, at most, two exercises daily—will be sufficient. Lenses correcting focal errors should be worn at the time of exercising. The exercise prisms in spectacle frames should be lowered and raised alternately every three seconds throughout the sitting. The object looked at may be anything that can be seen distinctly, and it should be distant from the observer not more than twenty feet nor less than ten feet. Looking at the object through the prisms, the externi are made to contract; raising the prisms, these muscles at once relax. Thus contraction and relaxation, rhythmic in character, are continued throughout the sitting. Exercise that fatigues does not build, hence the necessity of always stopping short of fatigue. A muscle develops as the result of exercise in proportion to the abundance of blood that can be brought into it. Abundance of blood supply means quick results; scanty blood

supply, because of smallness of the vessels supplying the muscle, means slow results. These conditions cannot be known beforehand; therefore it is better to tell the patient that the treatment will have to be continued for months.

Exercise of the externi that are attached, in greater part, below the horizontal plane, will exercise, at the same time, the inferior obliques, which would be good in a case of minus cyclophoria, but bad in a case of plus cyclophoria. If the externi have the ideal attachment—that is, half above and half below the transverse plane of the eye—exercise will always be well borne and will do good. If attached too high, the exercise of the externi will be associated with exercise of the superior obliques and will usually be well borne and ought to do good. These things can be known only as a result of exercise.

The object in view in exercising the externi is to so increase their inherent power that, under a normal impulse, they will be able to do a normal amount of work; that their tension may be inherent, not nervous, and sufficient to balance the inherent tension of the interni.

Operations.

No operation for pseudo-esophoria should ever be done. The kind depending on hyperopia should be treated by a full correction of the focal error; the kind due to subnor-

mal development of the ciliary muscles, making it necessary that the center controlling them shall generate an extraordinary nerve impulse, should be treated by gymnastic exercise of these muscles.

There can be drawn no unvarying line between operative and non-operative cases of intrinsic esophoria. If, under the red-glass test, there is homonymous diplopia, the case is almost certainly one to be operated upon; but the kind of operation is not shown by this test. If the esophoria at 16 inches is more than half the angle of convergence (nearly 9°) for that distance, the question of operation should be considered; and if it is much in excess of 5° in the near, there is no reason why an operation should be delayed. Whatever the quantity of esophoria in the distance, which is usually a little greater than that in the near, it should not be relied on exclusively when determining on an operation. Both the near and the far tests should always be noted. The quantity of error being sufficiently great to indicate an operation, the next thing to consider is the question as to whether the esophoria is sthenic or asthenic. More than 25° of adduction and more than 50° of adversion would indicate a partial tenotomy of one or both interni; there is nothing in esophoria that can justify a complete tenotomy. If the adduction is 25° or less and the adversion is 50° or less, no operation should be done on the interni, but one or

both externi should be shortened. If in doubt as to which of the two operations should be done, it would be safer to choose the shortening of an externus. Either operation would cure wholly or in part the imbalance—the partial tenotomy, by lessening the tension of the internus; the shortening, by increasing the tension of the externus. In properly selected cases either operation would establish a sthenic orthophoria; in unfortunately selected cases (those with normal or subnormal adduction) the tenotomy would establish an asthenic orthophoria, a danger never attending the operation of shortening.

Abduction in an operable case of esophoria is a safe guide in determining whether the operation should be done to lessen the tension of an internus or to increase the tension of an externus. If the abduction is above 5° or 6° and the abversion is but little below 50°, the internus should be cut; if abduction is below 5° and abversion is correspondingly low, the externus should be shortened.

In uncomplicated cases of esophoria, the error about equal in the two eyes, the operative effect should be divided between them. In such cases the plane of rotation must not be altered, hence the partial tenotomy must be central and the shortening must be straight forward.

When esophoria is complicated with only hyperphoria of one eye and cataphoria of the other, the operations on

the lateral muscles should be done as if there were no complications—that is, the tension of the muscles should be altered, but their planes should not be changed. Later the hyperphoria should be treated either by a permanent prism for the hyperphoric eye, by prismatic exercise of the weaker muscle of each eye, or by a central partial tenotomy of the superior rectus of the hyperphoric eye.

When esophoria is complicated by cyclophoria alone or by cyclophoria and hyperphoria, the operation done must not only alter the tension of the muscle, but must also change its plane of rotation. If the complication is plus cyclophoria alone and the operation is to lessen the tension of the internus, it should be so done as to elevate its plane of rotation. This is accomplished by a lower marginal tenotomy, leaving uncut the fibers at the upper margin. A threefold effect attends this operation: (a) the tension is lessened, (b) the cyclophoria is counteracted, (c) a hyperphoria is created. For the reason that an operation on only one internus would give a hyperphoria to the corresponding eye, the operative effect should be divided between the two eyes, the operation on the one internus being as nearly as possible like the operation on the other. The two operations should cure the esophoria and the plus cyclophoria; but at the same time a double hyperphoria would be created, a con-

dition far less objectionable than the two errors for the cure of which the operations were done.

If the sthenic esophoria is complicated by plus cyclophoria, with hyperphoria and cataphoria, the operative effect should be confined, if possible, to the internus of the cataphoric eye and should consist of a division of the lower and central fibers, leaving uncut enough of the upper fibers to prevent an over-effect. The result of this operation would be threefold: (a) lessening or curing the esophoria; (b) counteracting the plus cyclophoria; (c) converting the cataphoria into a hyperphoria, thus giving the patient a double hyperphoria. If some of the esophoria should remain, it should be relieved by a central partial tenotomy of the internus of the other eye. A marginal tenotomy of this muscle should not be done, even if some of the plus cyclophoria and hyperphoria remained, for the reason that dividing its lower fibers would increase the hyperphoria while curing the cyclophoria. How to deal with any remaining cyclophoria and hyperphoria will be shown in the discussion of those conditions.

If the esophoria is asthenic and uncomplicated, one of the externi, if not both, should be shortened so as to increase its tension without changing its plane of action. If complicated by a hyperphoria of one eye and a cataphoria of the other, there being no cyclophoria, the shortening of the externi should be done as if no compli-

cation existed; that is, the tension should be increased, but the plane should not be changed. If complicated by a plus cyclophoria only, both externi should be shortened to the same extent and the plane of each should be lowered sufficiently to effect a correction of the cyclophoria. The alteration of the tension would cure the esophoria. If the complications are plus cyclophoria and a hyperphoria of one eye and a cataphoria of the other, the operative effect, if possible, should be limited to the hyperphoric eye, and should be accomplished by a shortening of the externus so as both to alter its tension and to depress its plane of action. The triple effect would be: (a) increased tension for the esophoria; (b) lowered plane for the plus cyclophoria; (c) lowered plane for the hyperphoria, converting it into a cataphoria, so that there would be a double cataphoria. If any remaining esophoria should require a shortening of the externus of the other eye, the operation should be done so as to increase its tension without changing its plane, even if there should also remain, from the first operation, some of the plus cyclophoria and some of the cataphoria; for a change of the plane of action that would lessen one of these complications would increase the other.

The complication of minus cyclophoria has only been mentioned, for the reason that it is so rare. When it does exist in connection with esophoria, every step for

changing the muscle plane, as set forth in the treatment of a plus cyclophoria, must be reversed.

The operation of shortening an externus, when enough increase of tension can be had, should always be preferred to an advancement. While this can be done in nearly all cases of asthenic esophoria, in which an increase of tension of the externi is always indicated, nevertheless, in some cases these muscles have their attachment so far removed from the corneo-scleral junction that the advancement operation becomes clearly indicated. The same rules as to alteration of tension and change of plane apply to advancements as have been set forth in connection with shortenings. For the technic of these operations, and the after-treatment, the reader is referred to that part of Chapter III. in which these operations are described.

While doing these operations the judgment of the operator must decide as to their extent. His judgment cannot be good unless he keeps in mind the exact nature of the conditions for the relief of which he is operating. The true essence of these conditions cannot be known except as a result of the most skillful and careful use of the phorometer, cyclo-phorometer, and tropometer or perimeter. Before any operation is done, the refraction of the eyes should be determined, under a mydriatic, by means of the standard objective and subjective tests.

The operator should always be careful not to do too much; for it is far better to leave the patient with some of his esophoria than it is to give him the smallest quantity of the opposite error—exophoria. The danger of resorting to tests while operating is that it may lead to the doing of too much. Tests while operating cannot be reliable, and should, therefore, be avoided. When more than one operation is needed, it is better to allow from two to four weeks to intervene; but in errors of high degree, two operations, a partial tenotomy of an internus and a shortening of the opposing externus, or a partial tenotomy of both interni, or a shortening of both externi, may be done at the same time.

The object of partial tenotomies of the interni, in the treatment of esophoria, is to so *reduce* their tension that the externi, under a normal impulse, may perfectly balance them in action. The object of shortening the externi is to so *increase* their inherent tension that, under a normal impulse, they may perfectly balance the interni. In either case the *nervous* tension of the externi would be relieved.

Whenever an intrinsic esophoria has been reduced by operations so that the remainder can be cured by non-operative means, these should be resorted to, but not until the muscles operated upon have had time to completely recover from the operations.

CHAPTER V.

EXOPHORIA.

As the word indicates, there is, in exophoria, a *tendency* on the part of the external recti muscles and their synergists to make the visual axes deviate from the point of fixation. If this tendency were not counteracted by antagonists of the externi, the visual axes would either intersect beyond the point of fixation, or they would become parallel or even divergent. Abnormal nervous tension of the interni and their synergists counteracts the inherent tension of the externi and their synergists, so that the tendency is not allowed to become a turning. The visual axes are thus forced to intersect at the point of fixation; and binocular single vision is maintained, but at the expenditure of an undue amount of nerve force. Exophoria, like esophoria, is of two kinds, intrinsic and pseudo. As to causation, the one kind is wholly different from the other, but the two often coexist. As to the results, the one is the same in kind as the other, but the treatment of the one is not at all similar to the treatment of the other.

Intrinsic Exophoria.—In this the externi have the advantage over the interni. This imbalance may be due to the fact that the externi are hyper-developed or that the interni are of subnormal development. It may be that the error is not in the size of the muscles, but in the nature of their attachment to the globe, the externi having their attachment nearer the corneo-scleral junction than normal, or that the interni are attached too far back; it may be that the externi are short and tense or that the interni are long and somewhat lax. When either of these conditions causes exophoria, the error may be greater in the one eye than in the other, though, as a rule, the exophoria is about equal in the two eyes. When there is a difference, the monocular phorometer quickly shows it.

It must be conceded that the cause of intrinsic exophoria may not reside in the muscles themselves, but may be found in an unequal supply of nerve force, the centers for the externi generating a quantity of nerve impulse greater than normal, or the third conjugate brain-center, of subnormal development, sending a weaker current to the interni.

An intrinsic exophoria can exist without there being a state of imbalance between the externi and the interni. The oblique muscles are always more or less powerful as abvertors. There is but little room for doubt that, in

some cases, they may be too short and tense, or they may be too large and powerful, or their attachments may be nearer the posterior pole than normal, so that, in either case, their abverting power would be increased. This increase may be sufficiently great to cause an exophoria, even when there is no cyclophoria.

Malformation of the orbits, only in the sense of their being too far apart, can cause an exophoria; but when this cause exists alone, the muscle imbalance cannot be great.

The superior and inferior recti may have their attachments so far toward the temples as to greatly lessen their power to help the interni, and thus become a factor in the production of exophoria.

Whether the one or the other of the several conditions named is the cause of exophoria, or whether two or more of them become factors in the production of this error, the treatment, whether surgical or non-surgical, must be directed toward the lateral muscles. As to surgical means, either the tension of the externi must be lessened or the tension of the interni must be increased. If brain-centers are structurally over-developed or under-developed, they must remain so always; if the obliques, because of structure, attachment, or innervation, abvert too powerfully, they cannot be changed; if the orbits are too wide apart, surgery cannot bring them closer to-

gether. If the superior and inferior recti, because of faulty attachments, are feeble advertors, they must not be subjected to operations on this account. For these reasons it becomes apparent that any and every treatment of intrinsic exophoria, whatever may be the cause, must be directed toward the externi or toward the interni. An exophoria that is wholly muscular, all innervation centers being normal, will show the same number of degrees in the near as in the far.

Intrinsic exophoria is of two kinds, sthenic and asthenic. The quantity of the error does not determine its character. Only the abduction and the abversion tests, in any given case, can tell the operator that the error is sthenic or that it is asthenic. Exophoria with abduction of less than 8° and abversion of less than 50° is asthenic, and clearly indicates that the externi should not have their tension lessened, and just as clearly indicates that the interni must have their tension increased. Exophoria with abduction of more than 8° and abversion of more than 50° is sthenic, and the case should be treated with the view of lessening the tension of the externi.

Tests in myopic and emmetropic cases will always show the full amount of intrinsic exophoria in the far. In the near test of a myope, the intrinsic exophoria will have the associated pseudo-exophoria added to it. If the emmetrope does not show the same exophoria in the near

as in the far, it is increased or diminished because of an abnormal development of the ciliary muscles. If the ciliary muscles are hyper-developed, there will be more exophoria in the near than in the far, for the reason that an impulse less powerful than normal is required of the brain-center controlling them, so that a correspondingly slight associated impulse is sent to the interni. If the ciliary muscles are subnormally developed, they will require an impulse more powerful than the normal, and a correspondingly strong associated impulse must be sent to the interni, causing a pseudo-esophoria, which, to a certain extent, would neutralize the intrinsic exophoria.

The hyperope will always show less than the full amount of intrinsic exophoria in both the far and the near tests, for the reason that hyperopia always has a pseudo-esophoria associated with it, which neutralizes in part an existing intrinsic exophoria.

PSEUDO-EXOPHORIA.—There can be but two causes for this condition. One is myopia, or myopic astigmatism; the other is hyper-development of the ciliary muscles, making it necessary for the centers controlling them to generate a less powerful nerve current than would be required by these muscles if normally developed.

When the cause is myopia, or myopic astigmatism, the pseudo-exophoria shows itself only in the near, and is due to the fact that the guiding sensation calls either for

no nerve force to excite ciliary action or for a quantity less than is required by an emmetrope, depending on the amount of the focal error; and a correspondingly slight associated impulse is sent to the interni. If the point of view is 16 inches distant, there should be 1.8° of pseudo-exophoria for each dioptre of myopia up to 2.50 D, and .9° for each dioptre of myopic astigmatism up to 5 D. This kind of pseudo-exophoria does one of three things: (a) it increases an intrinsic exophoria in the near, (b) it shows an exophoria in the near when there is real orthophoria, or (c) it lessens an intrinsic esophoria in the near.

When the pseudo-exophoria is due to a hyper-development of the ciliary muscles and the patient is an emmetrope, the error will show itself only in the near test. If a 1.50 D impulse is all that is necessary to effect a 3 D contraction of the ciliary muscles, the pseudo-exophoria, with the test object at 13 inches, should be 2.7°. This may manifest itself in the same three ways as that caused by myopia. Strictly speaking, a pseudo-exophoria cannot exist in a hyperope; although, as shown in the chapter on esophoria, the hyperope who has hyper-developed ciliary muscles will show a less amount of pseudo-esophoria than would be shown if these muscles were of normal development. The difference in amount is equivalent to pseudo-exophoria.

When the far test shows orthophoria and the near test shows exophoria, the error is pseudo in character, and is dependent on one or other of the two causes above mentioned; and the same is true when an exophoria is less in the far than it is in the near. The same explanation applies when there is esophoria in the far and exophoria in the near. If in an emmetrope there is more exophoria in the far than there is in the near, the ciliary muscles are subnormally developed, and require an excessive impulse to make them perform their work. The associated impulse to the interni is correspondingly great.

There is a form of exophoria not yet referred to in this chapter, and probably not fully set forth in any book. The cause unquestionably resides in the third conjugate innervation center, and is structural in character; in other words, the third conjugate innervation center is subnormally developed, and, for this reason, sends a feeble impulse to the interni. The most exaggerated manifestation of this condition would lead one to judge that this brain-center is entirely absent, for occasionally a case is seen who has no power of convergence. Such a person enjoys binocular vision in the distance, but has only monocular vision in the near. In such a case there is no adduction power, for the one visual axis cannot be made to approach the other. Abduction will be normal or even above the normal. Adversion is unimpaired, showing

that the fourth and fifth conjugate innervations have full sway. The abversion of the right eye equals the adversion of the left eye, and, *vice versa*, the abversion of the left eye equals the adversion of the right eye. In these movements the visual axes are kept parallel, as when the eyes are looking straight ahead. That the condition is congenital in most cases is shown by the fact that there is no diplopia in the near. This must be due to an acquired mental suppression of images that fall on the temporal half of the retina, or, at least, a portion of it. The power of mental suppression can be acquired only in the earliest years of life. Hansell & Reber speak of a patient in whom this loss of convergence power was acquired, the result of some disease process in the part of the brain in which is located the convergence center. It is reasonable to suppose that this center might be destroyed by disease. In such a case, however, diplopia would exist everywhere except in the distance.

If the third innervation center can be entirely absent in one person and be present and fully developed in another, it is reasonable to conclude that in still another it may be present, but in a state of subnormal development. There may be as many different grades of development of this as there are individuals; but in the majority of persons this center is able, doubtless,

to generate 1° of impulse for every 1° of convergence, in association with the center of the ciliary muscles.

Subnormal development of this center must manifest itself in an exophoria in the near many degrees in excess of the exophoria in the far (of itself it can never cause exophoria in the far, but it may be associated with some of those conditions that cause intrinsic exophoria); or, if there is orthophoria or even slight esophoria in the far, there will be considerable exophoria in the near. The two ordinary causes of pseudo-exophoria—that is, myopia and hyper-developed ciliary muscles—will not cause more than 5° of the error. A greater degree of variation between the far and the near tests than this, in the exophoric direction, must be attributed to a subnormally developed third conjugate brain-center. A diagnostic feature of this condition is the manifestation of very low abduction power—much lower than is found in intrinsic exophoria of the same degree.

It is barely possible that a failure of connection between the ciliary center and the convergence center accounts for the absence of convergence power in some cases; and a slight connection may account for a feeble convergence.

Tests.

The cover test, allowing the eye to turn toward the temple, will be attended by a resetting of the eye to-

ward the nose when the cover is removed, and the false object will move rapidly toward the corresponding side until fused with the true object. The examiner can often see the resetting of the eye, but not so readily as an intelligent patient can detect the apparent movement of the test object.

The red glass, in the higher grades of exophoria, will develop crossed diplopia. The distance between the red light and the true light will give a fair idea of the quantity of the error. This test, resulting in crossed diplopia, practically always indicates operative treatment; but since it does not show whether the case is sthenic or asthenic, it cannot indicate the character of the operation to be done.

The double prism held before the right eye so that the two lights seen through it shall be in the same vertical line, the light seen by the left eye will be to the right, if there is exophoria. The extent of the error is shown by that prism, base toward the nose, that will place the middle light in line with the other two. This test, so far as it goes, is safe and accurate; but it cannot show whether the exophoria is sthenic or asthenic, and cannot, therefore, be relied upon in answering the question: "What operation, if any, shall be done?"

The single six-degree prism, held base up before the right eye, with the axis perfectly vertical, is as reliable

as the double prism, though one can never be so certain that the axis is vertical as he can be when using the double prism. The lower, or false, light will be on the opposite side—crossed diplopia. The prism, base in, that brings it directly under the true candle, measures the amount of the exophoria. Like the double-prism test, this one does not show whether the exophoria is sthenic or asthenic.

The rod test is less reliable in exophoria than in esophoria, for the reason that images displaced in the temporal part of the retinal fusion area seem to excite a greater demand for fusion than when displaced in the nasal part. Nevertheless, if the exophoria is sufficiently great, the rod held with its axis horizontal before the right eye will cause the streak of light to appear to the left of the candle. The prism, base in, that brings this vertical streak into the candle, measures, but not with accuracy, the exophoria. It always shows less exophoria than really exists. Maddox thinks that a red rod makes this test practically perfect, if, at the same time, a plain green or blue glass be held before the other eye.

The safe, sure, speedy, and easy test for exophoria is by means of the phorometer, and of all the phorometers the monocular is the most reliable in its results. The method of testing for exophoria is the same as that for esophoria, the position of the false object always deter-

mining whether it is the one or the other error. It is always on the opposite side in exophoria. The error is measured by revolving the rotary prism until the false object is brought under the true object, when the index will mark the quantity of the error. In the same way the other eye should be tested. In the phorometer test, as in all others, the exophoria at 16 inches should also be determined.

The next step is the taking of the abduction. This is the chief means for determining whether the exophoria is sthenic or asthenic. Unless the character of the error is known, it is not possible to resort to rational treatment. Whatever means may have been used in detecting the imbalance, the lifting power of the externi—abduction—must be taken.

This can be done, but not quickly nor accurately, by holding prism after prism, base in, before one eye, until the patient can no longer fuse the images. The chief objection to this method is the uncertainty about the axis of this prism being perfectly horizontal. The rotary prism of the phorometer, the instrument being perfectly leveled, is the quickest and best means for determining abduction or any other kind of duction. To test abduction with the rotary prism, the handle must be horizontal and the index must start from zero. Moving the index toward the temple it must be stopped the

moment the patient says the test object becomes double. The index stands opposite the number indicating the degree of abduction. If this is less than 8°, the exophoria is asthenic; if more than 8°, it is sthenic. If abduction is just 8°, since it would indicate that the tension of the externus should not be lessened, the exophoria should be classed as asthenic, from an operative standpoint.

Lastly, abversion should be taken either with the perimeter or the tropometer. This will usually be found less than 50° if abduction is low, and more than 50° if abduction is high.

While abduction and abversion are to be relied on most, adduction and adversion should always be taken. In fact, the study of no one muscle error is complete until all other errors have either been found or eliminated; and the individual strength of every muscle must be known. It is only in this way that the real nature of an exophoria can be known, and without this knowledge, rational treatment is impossible.

COMPLICATIONS OF EXOPHORIA.—These are the same as found in connection with the study of esophoria. They need only be mentioned here, as, under the head "Treatment," it will be shown how they modify the management of the exophoria. They are: myopia and myopic astigmatism, hyperopia and hyperopic astigmatism, and plus and minus cyclophoria. Thus it appears

that not only the relationship of every pair of muscles, and the condition of every individual muscle, must be known, but the refraction must also be understood, if one would deal successfully with exophoria.

Symptoms.

The subjective symptoms—or, more correctly speaking, the reflex nervous symptoms—caused by exophoria are those outlined in Chapter III. of this book, under the head "Symptoms of Heterophoria." The symptoms, whatever they may be, are not due to the inherent tension of the externi and their synergists, but to the nervous tension of the interni and their synergists, necessary for maintaining binocular singular vision. A symptom of which exophorics very commonly complain is a blurring or running together of the letters of the printed page, after more or less prolonged reading. At such times the reader feels compelled to close the eyes tightly before resuming his reading. Another symptom, often present when near work is being done, is a heavy, sleepy feeling of the upper lids, also a stiff feeling of the upper lids, as if they were adherent to the globes. Prolonged near work congests the margins of the lids, even developing a marginal blepharitis, more commonly in exophoria than in any other form of heterophoria. A drawing sensation on the nasal side of the

eyes is often complained of. There is no facial expression or pose of the head that is peculiar either to exophoria or to esophoria.

Treatment.

Non-operative.—In pseudo-exophoria the cause should always be removed, if practicable, by non-operative means. The pseudo-exophoria caused by myopia and found only in the near, when it serves to neutralize a part of an inherent esophoria, should be allowed to continue until the esophoria has been cured by prisms in positions of rest, by exercise of the externi, or by operations. By the non-treatment of a pseudo-exophoria of this character is meant that the myopic correction should not be worn in near work. For distant seeing the myopic correction should always be worn, for it neither adds to nor diminishes any form of heterophoria. If a myope is orthophoric for distance, the concave lenses should be worn for all purposes. With the lenses on for distant seeing there will still be orthophoria; with them on in near work the pseudo-exophoria is relieved and the patient becomes orthophoric in the near as well. If the myope is exophoric in the distance, the concave lenses should be worn for all purposes. The distant test will show the same exophoria with and without the lenses. In the near test without the lenses, the exophoria shown will be the intrinsic plus the pseudo; and with the

lenses will be only the intrinsic, the pseudo-exophoria having been cured by the establishment of the normal relationship between the center of convergence and the center of ciliary action.

The pseudo-exophoria caused by over-development of the ciliary muscles, requiring less than a 1 D impulse to effect a 1 D contraction of these muscles, is best treated by the wearing of concave lenses, only in the near if the patient is an emmetrope, but both in the far and in the near if the patient is slightly hyperopic. By so doing a pseudo-esophoria is developed which lessens the exophoria. If the diagnosis is correct—that is, if the exophoria is wholly or in part pseudo—the wearing of concave lenses will be attended by a source of relief. When they cause discomfort, they should be discarded; for the exophoria is due to some other cause than hyper-development of the ciliary muscles.

It will be remembered by many that J. J. Chisolm, of Baltimore, was in the habit, for many years, of prescribing concave cylinders when his patients had hyperopic astigmatism. Although he did not so teach, nevertheless his patients that were benefited had exophoria. An esophoric patient would not have tolerated such lenses.

Patients who are hyperopic and have either pseudo or inherent exophoria should never be given the full

correction of the hyperopia, for the imbalance would be made worse. If the hyperopia is less than 2 dioptres and the exophoria in the near is more than 4°, no correction should be given; if more than 2 dioptres, only the excess should be corrected. After an exophoria has been cured by exercise or by operation, a full correction of the hyperopia may be given, but in most cases 0.50 D should go uncorrected.

What has been said of myopic and hyperopic corrections, in cases of exophoria, applies proportionately to astigmatic (myopic or hyperopic) corrections. How to deal with these errors when there is a complicating esophoria has been emphasized in Chapter IV.

Those unfortunate subjects who have no converging power, probably because of absence of the third conjugate innervation center, cannot be relieved by either lenses, prisms, exercise, or operations.

Inherent Exophoria.—The treatment of the two forms of inherent exophoria is the same, so far as concerns non-operative means. The first of these is prisms in positions of rest (bases in) for the weak interni. The full correction of exophoria by prisms should not be attempted; probably only a half correction of the error should be given. Maddox suggests a correction of half or a third of the distant and a quarter of the near exophoria. When there is no complicating cyclophoria, the

prismatic effect should be equally divided between the two eyes, and the axes of the prisms should be perfectly horizontal. The same rule holds good when there is a hyperphoria of one eye and a cataphoria of the other. If there is a complicating plus cyclophoria without any hyperphoria, the prismatic effect should be equally divided between the two eyes; but the axis of each should be tilted down at the temporal end, so as to make the externi tort the eyes in while turning them out to fuse the displaced images. The axes should be tilted in the opposite direction if the complication is a minus cyclophoria. When the complication is a plus cyclophoria with a right hyperphoria and a left cataphoria, the exophoric prism should be placed only before the hyperphoric eye and its axis should be tilted down at the temporal end. The muscular action necessary for overcoming the prism will turn the eye out and down and tort it in. If discomfort results, it will be due to the work that the inferior rectus has had to do to overcome the prismatic displacement. If any prism is placed before the left (cataphoric) eye, its axis should be perfectly horizontal, for, if tilted down at the temporal end, it would favor the cyclophoria, but increase the cataphoria; while, if tilted up, it would force a correction of the cataphoria, but would increase the plus cyclophoria. If there is doubt as to whether the axes of the exophoric prisms should

be tilted, it is better to place them exactly horizontal. Weak exophoric prisms, with their axes perfectly horizontal, should bring some relief to most patients. When they do not relieve, it thus becomes evident that one externus, if not both, is attached too high, and there is developed a plus cyclophoria.

The objection raised against esophoric rest prisms, that they interfere with the law of direction, applies with equal force to prisms in positions of rest for exophoria.

Decentration of lenses, in for convex and out for concave, will accomplish the same results for exophoria as will prisms with bases in. The rules for decentration are given in Chapter IV.

Exercise Treatment.

There are two useful methods of exercising the weak interni in cases of exophoria. The simplest, if not the best, and certainly the cheapest, is the candle exercise. The candle is mentioned for the reason that the images of its blaze stimulate the two retinas so as to make it more certain that the center of convergence will be excited sufficiently to converge the visual axes, as the candle is brought from arm's length to a point six or seven inches from the eyes. Images less bright, such as those of a pencil, in some cases would not sufficiently stimulate. The

method of conducting the candle exercise is sufficiently set forth in Chapter III., to which the reader is referred. If properly conducted and continued sufficiently long, it will do good in all cases except those in whom the interni have attachments too high on the globes. Interni thus attached, when exercised either with the candle or by means of prisms, will call into simultaneous action the inferior obliques, that they may prevent the convergence of the vertical axes of the eyes. In the greater number of cases this would either add to or develop a plus cyclophoria while curing the exophoria. The patient would not be benefited. But when the interni have the ideal attachments, or even when they are attached too low, the candle exercise, as well as prism exercise, will do good. In cases of ideal attachment only the interni are exercised; in cases with attachment too low every contraction of the interni is attended by a contraction of the superior obliques, so that development of the interni is attended by a corresponding development of the superior obliques—a thing to be desired in many cases.

The rapidity of a cure of exophoria by the candle exercise depends in part on the quantity of the exophoria and in part on the character of the blood supply of the interni; abundant blood supply means quicker results. Gentle rhythmic exercise will increase the size and power of a muscle, whether voluntary or involuntary.

Permanent results follow such a method. No one can doubt that a muscle can be developed; there is reasonable doubt if a nerve center can be developed as a result of either mild or severe stimulation. A nerve cell is very different from a muscle fiber.

Prism Exercise.

There are two methods of exercising the interni by means of prisms. The one is gentle rhythmic exercise by means of weak prisms with their bases out; the other method is that first suggested by Deady, and later advocated by Gould—loading the convergence by means of the strongest prisms possible. The former is intended for the strengthening of the muscles themselves, while the latter is designed to stimulate the convergence center to greater activity. The advocates of the latter method claim that exophoria, in most cases, is purely innervational and should be cured by forced stimulation of the convergence brain-center, the third conjugate innervation center. That this center is susceptible to excessive stimulation cannot be denied, but it is doubtful if this should be done. It is certainly more rational to develop the interni so as to make them respond normally to the impulse that the brain-center can easily generate in its real, though it may be subnormal, state of development. If it were possible to

enlarge the capacity of a brain-center, as it is possible to increase the size and power of a muscle, the Deady method would not be objectionable. The reader is again referred to Chapter III., where the method is described.

In the rhythmic exercise of the interni by prisms, the design is to produce slight contractions by means of weak prisms (from 1° to 8°) with their bases out, to be followed by complete relaxation, each contraction and relaxation to last about three seconds, throughout a sitting of not more than ten minutes. The exercise should always stop short of fatigue, for exercise that tires does not build. To get practically complete relaxation, the object of fixation should be twenty feet distant. Persistent exercise, after this method, in low degrees of inherent exophoria, will produce permanent results. This method is fully set forth in Chapter III.

In high degrees of intrinsic exophoria, non-operative measures will be productive of but little, and that little will be slow of accomplishment. Exophoria in the distance of 4° or more, and an exophoria in the near equal to the angle of convergence at that point, give little promise of yielding to non-operative means. An exophoria that gives diplopia in the distance under the red glass test, is practically always a case for surgical treatment. All cases not showing good results, in a reasonable length of time, under non-oper-

ative measures, should be given the advantage offered by skilled surgery.

The object in view when exercising the interni in exophoria is to so develop them that they may respond normally to a normal nerve impulse—1° of contraction for every degree of impulse.

Operative Treatment.

Before any operation for exophoria is done, the possibility of a cure by non-operative means should be eliminated, and the condition of every extrinsic ocular muscle should be known. Complicating muscle imbalances must be taken into account, and, if possible, should be corrected by the operations for the exophoria. In uncomplicated cases of exophoria, and in cases complicated only by hyperphoria of one eye and cataphoria of the other, the operations must either diminish the tension of the externi or increase the tension of the interni. When the exophoria is complicated by a cyclophoria, not only must the muscle tension be altered, but the muscle plane must also be changed.

In sthenic exophoria the externi should be first subjected to the operation of partial tenotomy, with the view of reducing their tension. The case being uncomplicated, the tenotomy should be central. The operative effect should be equally divided between the two externi,

and should not be so extensive as to reduce abduction below 8° or abversion below 50°. In no case of exophoria should a complete tenotomy of an externus ever be done, for the reason that the risk of reducing both the duction and version power below the normal would be too great. After the two partial tenotomies, any remaining exophoria that cannot be cured by non-operative measures should be still further relieved by a straightforward shortening of one or both interni, with the view of increasing tension without changing the plane of rotation.

When there is a complication of hyperphoria and cataphoria only, the operations, whether partial tenotomies or shortenings, should be done as if no complication existed. At some other time the vertical error must be given the proper treatment.

A sthenic exophoria that is complicated by a plus cyclophoria only should be treated with the view of lessening the tension of both externi and lowering their planes of action. This would be accomplished by cutting the upper and central fibers of each externus as nearly alike as possible, leaving the lower fibers intact. The threefold effect of these two operations would be: (a) lessening or curing the exophoria; (b) correction, wholly or in part, of the plus cyclophoria; (c) the production of a double cataphoria.

A sthenic exophoria complicated by a plus cyclophoria and a right hyperphoria and left cataphoria should be subjected first to a partial marginal tenotomy of the externus of the hyperphoric eye. The operation of cutting the upper and central fibers of this externus would be attended by these three results: (a) lessening of the exophoria; (b) a partial or complete correction of the plus cyclophoria; (c) the production of a cataphoria equal to, or a little less than, the cataphoria in the other eye. If any remaining exophoria should still be complicated with plus cyclophoria and left cataphoria, the second operation should be a shortening of the left internus in such a way as to both increase its tension and elevate its plane of action. This would have three results: (a) still further diminishing, if not curing, the exophoria; (b) a further correction of the plus cyclophoria; (c) an elevation of the cataphoric eye so as to bring it as nearly as possible in the same horizontal plane with the eye that was primarily hyperphoric. Should the first operation cure the complicating plus cyclophoria, even if the hyperphoria were not cured, the remaining exophoria should be relieved by a central partial tenotomy of the externus of the left eye, which would alter its tension without changing its plane of action.

Asthenic exophoria uncomplicated should be treated by straight-forward shortening of both interni, the op-

erative effect being as equally divided between them as possible. In this way their tension would be increased, but their planes of rotation would not be changed. The same operations should be done when the exophoria is complicated by hyperphoria and cataphoria. Operations for a lateral error should attempt the simultaneous correction of a vertical error only when there is a complicating cyclophoria.

Asthenic exophoria, complicated by a plus cyclophoria only, should have both conditions relieved by shortenings of both interni in such a way as to increase their tension and elevate their planes. The triple effect would be: (a) correction of the exophoria; (b) cure of the plus cyclophoria; (c) the production of a double hyperphoria. When the complication is not only a plus cyclophoria, but a right hyperphoria and left cataphoria as well, the first operation should be a shortening of the left internus in such a way as to both increase its tension and elevate its plane. These would be the effects of this operation: (a) correction, wholly or in part, of the exophoria; (b) a partial or complete cure of the cyclophoria; (c) the production of a double hyperphoria. If the internus of the right eye must be operated upon, the shortening must be straight-forward, even if the two complications still existed; for an elevation of its plane would increase the hyperphoria while lessening the plus cyclophoria, and

lowering its plane would increase the cyclophoria while diminishing the hyperphoria.

If a minus cyclophoria, which is rare, should alone complicate an exophoria, the marginal tenotomies of the externi would be below, and the shortenings of the interni would have to be done so as to depress their plane of rotation. If the minus cyclophoria with a hyperphoria and cataphoria should complicate an exophoria, a lower marginal tenotomy of an externus should be performed only on the externus of the cataphoric eye; while a shortening of an internus with depression of its plane should be done only on the internus of the hyperphoric eye, for reasons that are apparent.

The chief object in operating for exophoria, whether the operation be partial tenotomies of the externi for sthenic exophoria or shortenings of the interni for asthenic exophoria, is to so change the relative tension of the interni as to enable them to respond normally to a normal impulse from the third conjugate innervation center—1° degree of convergence for every degree of impulse—and thus establish harmony between the externi and the interni.

The change of the plane of action, though of vast importance, depends solely on the existence of a complicating cyclophoria.

CHAPTER VI.

HYPERPHORIA AND CATAPHORIA.

These conditions can be studied intelligently only when the head is in the primary position, with the test object on the line of intersection of the extended median and horizontal fixed planes of the head. The object should be twenty feet distant from the eyes. If there is no imbalance of the vertically-acting muscles and the lateral recti are properly attached and the eyes are contained in orbits that have been normally developed, when the test object is fixed, the two visual axes will lie in the extended horizontal plane, with no tendency for either axis to rise above or dip below this plane. This will be shown under any one or all of the tests for determining the balance of the ocular muscles. Such a condition, as already noted in Chapter II., is vertical orthophoria. Hyperphoria is a tendency of one visual axis to rise above this plane, the actual turning easily occurring as soon as the eye is freed from the control of the guiding sensation, by any one of the tests to be given farther on. Cataphoria is a tendency on the part of one visual axis to fall below this plane, the tendency becoming a turning

so soon as the image has been changed in character or position so that no effort at fusion will be made. Usually a hyperphoria of one eye is associated with a cataphoria of the other, and the two errors are practically equal. Occasionally there will be found a case in which there is a vertical orthophoria of one eye and a hyperphoria or a cataphoria of the other. Less frequently there will be double hyperphoria or double cataphoria.

Any one of these errors makes it a difficult matter for the superior and inferior recti to obey the law governing them—to wit, they must keep the visual axes in the same plane, in order to help relate, properly, corresponding retinal points.

Causes.—There are several conditions that may cause a vertical imbalance. Since malformation of the orbits has been emphasized, in recent years, as a cause of hyperphoria, this will be studied first. Only in the sense of one orbit's being higher or lower than the other, can a malformed orbit be the only cause either of a hyperphoria or a cataphoria. Fig. 20 represents the median plane of the head, A B; the horizontal plane of the head, C D; and the two eyes. The right one is in a normal orbit, so that its vertical axis *gh* is parallel with the median plane of the head and its transverse axis *ef* is contained in the horizontal plane of the head. The left eye is represented as contained in a malformed orbit, in the sense that it is

lower than the fellow orbit; therefore the contained eye is lower than its fellow, as is shown by its transverse axis *ef* lying below the fixed horizontal plane of the head, C D. It will be seen that the vertical axis *gh* is parallel with the median plane A B. The muscles of these two eyes may be supposed to be perfectly balanced. Under the phorometer test of the vertically-acting muscles, the

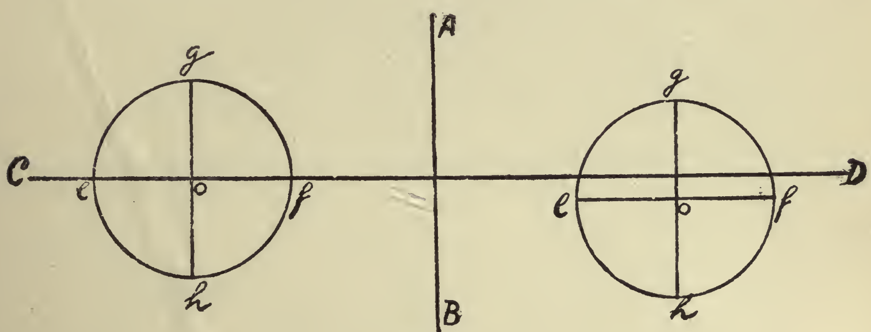

Fig. 20.

right eye would show orthophoria, but the left eye would show cataphoria. In binocular fixation of a point lying in the extended horizontal plane of the head, the visual axis of the right eye, the muscles being in a state of equilibrium, would point to the object; while the visual axis of the left eye would have to be raised by the superior rectus and inferior oblique, so as to intersect its fellow at the point of view. Thus elevated, its vertically-

acting muscles cannot be in a state of equilibrium. Under test this eye would drop into a state of equilibrium for all its muscles and would thus show cataphoria. No posing of the head would change the condition or lessen the error. The right eye under test would continue in its state of equilibrium, and would, therefore, show vertical orthophoria.

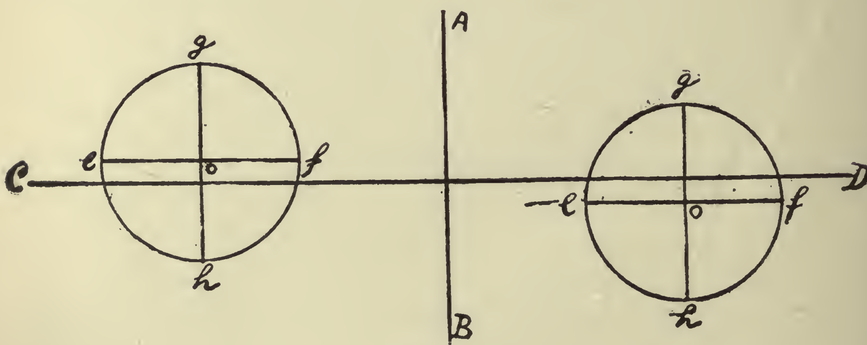

Fig. 21.

A figure could have been constructed showing the right eye in a normal orbit, with its axes properly related to the median and horizontal planes of the head; and the left eye in a malformed orbit, in the sense of its being higher than the fellow orbit, with its transverse axis *ef* above the fixed horizontal plane of the head, although its vertical axis *gh* would be parallel with the median plane. The right eye would show vertical ortho-

phoria, but the left eye would show hyperphoria. No posing of the head can change the relationship that these two eyes bear to the two fixed planes of the head.

Fig. 21 represents malformation of both orbits in the sense that the right one is too high and the left one is too low. The vertical axis of each eye is parallel with the median plane of the head, but the transverse axis of

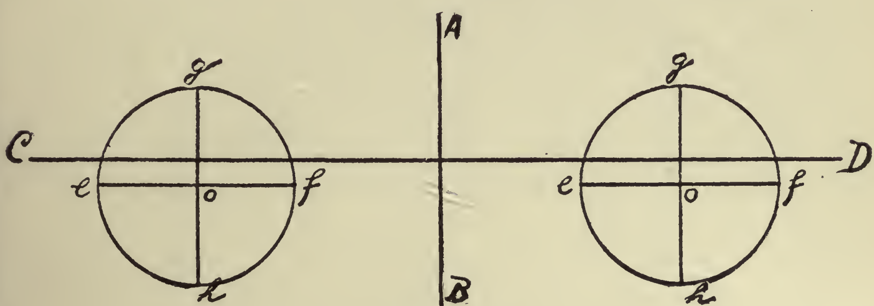

Fig. 22.

neither eye lies in the horizontal plane of the head; that of the right eye is above, while that of the left eye is below it, but both are necessarily parallel with it. The malposition of the right eye would give to it hyperphoria, while the malposition of the left eye would give to it cataphoria. A state of equilibrium of the vertically-acting muscles (granted to be normal) of the right eye would place its axis above, but parallel with, the extended horizontal plane of the head; while the same muscular state

of the left eye would place its visual axis below, but parallel with this plane. No pose of the head can help these eyes in the effort at binocular fixation.

Fig. 22 represents a pair of eyes that are set in malformed orbits, in the sense that both are too low; hence both of these eyes have their transverse axes below the horizontal plane of the head, but parallel with it. This

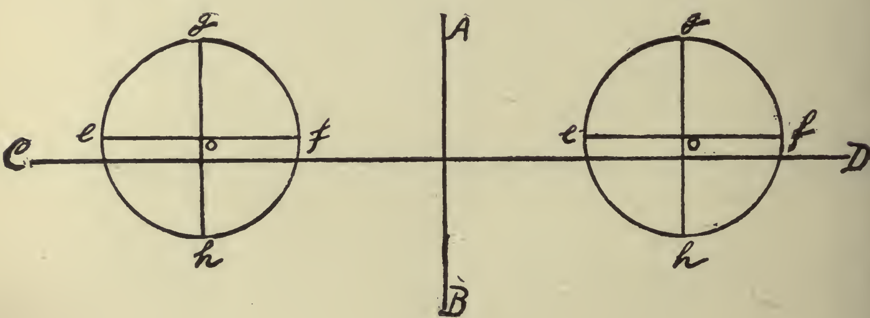

Fig. 23.

kind of malformation gives a double cataphoria, which can be detected with a fair degree of readiness by means of the monocular phorometer, but is more certainly and more easily shown by the proof test of hyperphoria—a double prism, the use of which, for this purpose, will be described under the head "Tests." A pose of the head cannot bring the transverse axes of the eyes into the horizontal plane of the head, but it can make vision easier.

The characteristic pose, in such cases, is an elevation of the chin. Such people are high-headed.

Fig. 23 represents a pair of eyes set in malformed orbits, in the sense that they are both too high. The vertical axes are parallel with the median plane of the head, but the transverse axes lie above the horizontal plane, though parallel with it. With the head in the primary position, a point in the extended horizontal plane and in the line of its intersection by the extended median plane cannot be fixed by these eyes without depression of the visual axes by contraction of the inferior recti, aided by the superior obliques. Under test, either one of these eyes not under control of the guiding sensation will turn up into the position of muscle equilibrium, showing a double hyperphoria.

In the study of all these figures, all of the muscles are supposed to be normal in development, correct in attachment, and perfectly innervated. A hyperphoria, single or double; a cataphoria, single or double; a hyperphoria of one eye and a cataphoria of the other, having malformations of the orbits as the sole causative agent, will not have a complicating cyclophoria; nor can any kind of malformation of the orbits ever cause cyclophoria. It has already been shown that orbits that are too wide apart cause exophoria, while orbits that are too close to each other will cause esophoria.

It should be remembered that other causes of hyperphoria and cataphoria may exist when eyes are set in malformed orbits, and that the other causes may show themselves in an increase of the error caused by the malformation of the orbit, or may neutralize it, or may even reverse it. To illustrate: the right orbit may be normal, the contained eye having its vertical and transverse axes properly related to the median and horizontal fixed planes of the head; while the left orbit may be too low, so that the contained eye has its transverse axis below the horizontal plane of the head (see Fig. 20). As a consequence, the muscles being well balanced, there will be a left cataphoria; but if the left superior rectus is too strong for its opposing inferior rectus, the cataphoria of orbital causation either will be neutralized or there will be a left hyperphoria.

When malformation of the orbits is the only cause for vertical imbalances, the resulting errors may be said to be pseudo-hyperphoria and pseudo-cataphoria. The treatment of such errors should be by means of prisms in positions of rest, of such strength as to fully correct the errors.

There is no direct connection between the brain-center for the ciliary muscles and those centers controlling the muscles that elevate and depress the eyes; so that, through these muscles, a focal error cannot cause a

hyperphoria or a cataphoria. It cannot be denied, however, that convex lenses given to correct hyperopia, sometimes cure a hyperphoria or a cataphoria. Such cases have always had a pseudo-esophoria which, likewise, was cured by the convex lenses. It is clear that in such cases one internus is attached too high or the other internus is attached too low, so that the one eye, on being turned in, is also turned up; while the other eye, on being turned in, is also turned down. The same agent (convex lenses) that relieved the in-turning (pseudo-esophoria) relieved also the up-turning (pseudo-hyperphoria) and the down-turning (pseudo-cataphoria). Both interni attached too high would give, under the same conditions, a double pseudo-hyperphoria; while both interni attached too low would give a double pseudo-cataphoria. There would also be a complicating cyclophoria, which will be studied more fully in Chapter VII.

In the same way it could be shown how a pseudo-exophoria, because of too high or too low attachment of one or both externi, might cause a pseudo-hyperphoria or cataphoria, one or both, or either in the double form, all of which would be relieved by concave lenses.

Hyperphoria and cataphoria, in the great majority of cases, are intrinsic, or inherent, in character. They are never pseudo except when caused by pseudo-esophoria and pseudo-exophoria, or malformed orbits.

The cause of an intrinsic vertical error may reside wholly in the interni, but only when there is an intrinsic esophoria or an intrinsic exophoria. In such cases of esophoria one or both interni are attached too high, or one or both are attached too low, or one is attached too high and the other is attached too low. In the one, the esophoria would cause a double hyperphoria and a minus cyclophoria; in the second case the esophoria would cause double cataphoria and plus cyclophoria; and in the last case the esophoria in one eye would cause a hyperphoria and a minus cyclophoria, and in the other a cataphoria and a plus cyclophoria. How to deal with such interni has been pointed out in the chapter on esophoria.

Intrinsic exophoria, in which the externi are attached too high, will cause double hyperphoria and plus cyclophoria; if both interni are attached too low, the exophoria will cause double cataphoria and minus cyclophoria. If one internus is too high and the other is too low, the exophoria of the former would cause hyperphoria and plus cyclophoria; the exophoria of the latter would cause cataphoria and minus cyclophoria. How to deal with the externi in such cases has been set forth in the chapter on exophoria.

Hyperphoria and cataphoria, in the greater number of cases, are caused by imbalance of the vertically-acting muscles—the supervertors and subvertors, which are the

superior recti and inferior obliques and the inferior recti and the superior obliques. When the cause is either in the straight or oblique supervertors or in the straight or oblique subvertors, the error is always inherent, and never pseudo.

Double Hyperphoria.—This condition may be caused by the two superior recti being hyper-developed, or by a subnormal development of the inferior recti; or it may be caused by the superior recti having their attachments too near the corneo-scleral junction, or by the inferior recti having their attachments too far removed from the corneo-scleral junction; or it may be that the first conjugate innervation center is normally so endowed as to send a more powerful impulse to the superior recti than goes to the inferior recti from the second conjugate innervation center. If either of these conditions is the cause of a double hyperphoria, there will also be a minus cyclophoria, independent of any imbalance of the obliques.

The superior and inferior recti may be well balanced, and the externi and interni may have ideal attachments, and yet there may be a double hyperphoria. The cause would be found in imbalance of the obliques, the inferior having the advantage over the superior, either because the former are more highly developed or because they are attached nearer the posterior pole or because the

seventh conjugate innervation impulse is more intense than that from the sixth conjugate innervation center. In either case the double hyperphoria would be associated with plus cyclophoria.

In double hyperphoria caused by the superior recti being too strong, the nervous tension of the inferior recti would counteract both the hyperphoria and the minus cyclophoria, while nervous tension of the superior obliques would help to counteract the hyperphoria, but would augment the minus cyclophoria. It is reasonable, therefore, to conclude that the counteracting nerve impulse in such a case is sent only to the inferior recti. Depressing the chin—a downcast face—would help relieve the inferior recti of nervous tension.

In double hyperphoria caused by the inferior obliques being too strong, nervous tension of the superior obliques would counteract both the hyperphoria and the plus cyclophoria, while nervous tension of the inferior recti would help to counteract the hyperphoria, but would increase the plus cyclophoria; hence the conclusion that the counteracting impulse, in such a case, is sent only to the superior obliques.

Such a patient would instinctively elevate the chin—carry a high head—to relieve the nervous tension of the superior obliques. The most advantageous position of the eyes for the in-torting action of the superior

obliques is a depression of the visual axes below the fixed horizontal plane of the head; the greater this depression of the visual axes (elevation of the head), the more powerful the in-torting action of the superior obliques.

DOUBLE CATAPHORIA.—This condition may be the result of hyper-development of the inferior recti or subnormal development of the superior recti, or it may result from the inferior recti having their attachment too far forward or from the superior recti being attached too far back; or it may be caused by a more powful impulse sent from the second conjugate innervation center to the inferior recti than is generated by the first conjugate center for the superior recti. In either case the double cataphoria will be associated with plus cyclophoria. Nervous tension of the superior recti will counteract both the cataphoria and the plus cyclophoria; while nervous tension of the inferior obliques would counteract the cataphoria, but would increase the plus cyclophoria. Hence, in cases like the above, the corrective nerve impulse must be sent only to the superior recti. The position of the eyes most favorable for effective action of the superior recti is a depression of the visual axes below the horizontal plane of the head; hence such patients will carry their heads high, so as to lessen the nervous tension of the superior recti.

Double cataphoria may be caused by imbalance of the obliques, the superior being stronger than the inferior, either because the former are hyper-developed or the latter are subnormally developed, or because the former are attached nearer the posterior pole, or because the sixth conjugate innervation is more powerful than the seventh. In either case the double cataphoria would be associated with minus cyclophoria. The corrective nerve impulse would be sent to the inferior obliques, which would counteract both the double cataphoria and the minus cyclophoria. The position of the eyes most favorable for corrective action of the inferior obliques is an elevation of the visual axes above the extended horizontal plane of the head; hence such patients would have their faces downcast, for this pose of the head would help to relieve the nervous tension of the inferior obliques.

Hyperphoria of one eye and cataphoria of the other, independent of malformation of the orbits and faulty attachments of the lateral recti muscles, are always inherent in the vertically-acting muscles, and never innervational. For convenience of study the right eye will be considered as hyperphoric and the left eye as cataphoric, although the reverse is often found. The right hyperphoria is due to the fact that the superior rectus is too strong for its direct antagonist, the inferior rectus, or that the inferior oblique is too strong for the superior

oblique; or both of these conditions may unite in the development of the hyperphoria. If the superior rectus alone is the cause of the hyperphoria, it is because this muscle is hyper-developed or that the inferior rectus is of subnormal development, or that the superior rectus is attached too near the cornea or that the attachment of the inferior rectus is too far removed from the cornea.

The hyperphoria would be sthenic if the superior rectus is hyper-developed or is attached too near the cornea; it would be asthenic if the inferior rectus is subnormally developed or is attached too far away from the cornea. In either case the hyperphoria would manifest itself in association with minus cyclophoria.

If the inferior oblique alone is the cause of the hyperphoria, it is because of hyper-development of this muscle or a subnormal development of the superior oblique; or because the inferior oblique is attached too far behind the equator or the superior oblique is attached too near the equator. The hyperphoria thus caused is sthenic in cases in which the inferior oblique is hyper-developed or is attached too far behind the equator; it is asthenic in those cases in which the superior oblique is subnormally developed or is attached too close to the equator. In either condition the hyperphoria would show itself in association with plus cyclophoria.

When the hyperphoria manifests itself unassociated with either minus or plus cyclophoria, it becomes evident that both the superior rectus and inferior oblique enter into the causation.

The left eye under test will show cataphoria, usually the same in quantity as the hyperphoria of the right eye. The cataphoria is caused by either a too powerful inferior rectus or a too powerful superior oblique; or both of these muscles may unite in the production of the cataphoria.

In a case in which the inferior rectus alone is the causative agent, it is either hyper-developed or has its attachment too close to the cornea; or its direct antagonist, the superior rectus, is subnormally developed or is attached too far away from the cornea. The cataphoria would be sthenic if the inferior rectus is either hyper-developed or is attached too near the cornea; it would be asthenic if the superior rectus is under-developed or has its attachment too far removed from the cornea. In either case the cataphoria would be associated with a plus cyclophoria.

In a case in which the superior oblique is the sole cause of the cataphoria, it is either because it is hyper-developed or because it has its attachment too near the posterior pole; or because its direct antagonist, the inferior oblique, is subnormally developed or is attached

too near the equator. The resulting cataphoria is sthenic in those cases in which the superior oblique is either hyper-developed or is attached too near the posterior pole; it is asthenic when the inferior oblique is under-developed or is attached too near the equator. In either case the cataphoria would be associated with a minus cyclophoria. Cataphoria will be unassociated with either plus or minus cyclophoria only when both the inferior rectus and superior oblique are united in the causation.

Nervous tension of the inferior rectus counteracts the right hyperphoria, if caused by the superior rectus; while nervous tension of the superior rectus will counteract the left cataphoria, if caused by the inferior rectus. Not only will the right hyperphoria and left cataphoria be thus neutralized, but the minus cyclophoria of the right and plus cyclophoria of the left would be suppressed by the nervous tension of the same muscles. The corrective impulse would come not from one conjugate center, as in double hyperphoria and double cataphoria, but from two separate centers.

Nervous tension of the superior oblique counteracts the right hyperphoria which is caused by the inferior oblique, while nervous tension of the inferior oblique will counteract the left cataphoria that is caused by the superior oblique. The plus cyclophoria of the right eye and the minus cyclophoria of the left eye will be sup-

pressed by the nervous tension of the same muscles that counteract the hyperphoria and cataphoria.

TESTS.

The phorometer, with perfectly adjusted prisms and spirit level, alone can be depended on in testing for hyperphoria and cataphoria. The slightest error in testing will be followed by bad results in practice. In attempting to test for these errors by means of a displacing prism with its axis horizontal, held in the hand, one would have to be very careful or the axis would be slightly inclined in one direction or the other; so that, if the eye under test is hyperphoric and the temporal end of the prism inclines down, the error will be exaggerated, and if it inclines upward, the hyperphoria would be neutralized more or less completely, or even a cataphoria might be shown.

For reasons already given the rod test is not to be trusted implicitly, but it is much to be preferred over the hand-prism test, or even the prism when set in the trial frame of the refraction case. The test object being a candle, a rod held with its axis vertical before one eye will show the streak of light which, in orthophoria, should pass directly through the blaze seen by the other eye; in hyperphoria, the streak would pass below the blaze, while in cataphoria it would pass above the blaze.

In the low degrees of vertical heterophoria, the streak falling on the area of binocular fusion will excite some effort, however small, at fusion. In the higher errors, the prism used for measuring the amount of the error, by throwing the streak on the fusion area, would excite some effort at fusion. When the rod is the means of testing, the error is never shown in excess, and for this reason is more safe than accurate.

The use of the plus 13 D lens before one eye, if not worthy of trust in the examinations for esophoria and exophoria, would certainly be less trustworthy in examinations for hyperphoria and cataphoria.

In high degrees of a vertical error the plane red glass held before one eye will cause diplopia, the red light below in hyperphoria and above in cataphoria. When the red image is entirely outside the area of binocular fusion, the full error will be shown, but cannot be accurately measured, for the reason that the rotary or other prism that carries the red image into the fusion area, at once excites some effort at fusion. Like the rod test, the red-glass test will mislead only in that it will not show, even on careful measurement, the full error.

The cover test will show the vertical errors, but no one would think of basing the treatment of a case on this test.

Any of the standard phorometers may be used in testing for vertical heterophoria, but in this the monocular

instrument is most useful and trustworthy. The 10° prism, base in, should be placed in the cell behind the rotary prism; the controlling screw should be vertical, and the index should stand at zero. The instrument should be perfectly level. The patient's head should be in the primary position. The test object should be a white spot on a black background, and should be distant twenty feet. With the instrument before the right eye there will appear to be two spots, the true one to the left and the false one to the right. If they are too widely separated, as in cases that are esophoric, the 6° prism should be substituted for the 10° prism. The patient should constantly fix the *true* spot, and by indirect vision alone should locate and relate the *false* spot. If the eye is hyperphoric, the false spot will be lower than the true; and since its image is not on the area of binocular fusion, the full error will be shown. The index of the rotary prism moved upward will accurately measure the error; for in carrying the false object up to the level of the true, the image of the former is not made to invade the fusion area, provided the true object alone has been fixed throughout the test.

The vertical imbalance of one eye having been taken, the phorometer should be turned in front of the other. Precisely the same steps should be taken in determining the condition of its vertically-acting muscles. Hyper-

phoria having been found in the eye first tested, the fellow eye, as a rule, will be found cataphoric. The false object will appear higher than the true. The index of the rotary prism should be carried downward until the false object reaches a level with the true object. The quantity of the error, as indicated on the scale, should be noted. In the greater number of cases the degree of cataphoria will be the same as the hyperphoria of the other eye.

One eye having shown hyperphoria, the other may show vertical orthophoria or even hyperphoria. The eye under test, seeing the false object by indirect vision, does not receive any fusion stimulus; hence it always turns into the position of equilibrium of all its muscles. For this reason it is just as easy to determine the existence of a double hyperphoria, with the monocular phorometer, as it is to ascertain the existence of any other form of heterophoria. The patient must be impressed with the absolute importance of always *fixing* the true object—that is, must see it by direct vision.

Whether one or the other of the tests referred to above should be adopted, the proof test for vertical imbalance should not be neglected. Errors that may have crept in because of carelessness of the operator or indifference of the patient can be eliminated easily by the proof test. The means of *proving* is the Maddox double

prism (4° to 6° each). This should be held in the hand first before one eye and then the other, so that the line of union of the prism bases shall be horizontal. The fixing eye should be the one not under test. The prism should be moved up and down before the eye under test, so that one moment the false object would be seen below the true and the next moment above it, but always by indirect vision. If the distance from the true to the false object is the same when below as it is when above, there is vertical orthophoria. If there is hyperphoria, the false object, when seen through the upper prism, will be closer to the true object, by twice the amount of the error, than when seen through the lower; while the reverse will be true if there is cataphoria. In double hyperphoria the objects will be closer together for each eye when the false object is seen through the upper prism; while in double cataphoria the false object, when seen through the lower prism by each eye, will be nearer the true object than when seen through the upper prism. If there is hyperphoria of one eye and cataphoria of the other, when the double-prism proof test is applied to the hyperphoric eye, the false object seen through the upper prism will be close to the true, and will be farther removed from it when seen through the lower prism. On shifting the test to the other eye, the false object seen through the lower prism will be nearer

the true than when it is seen through the upper prism. The double prisms should be of equal strength, and each should be strong enough to throw the image of the test object entirely above or below the limits of the field of fusion.

Dr. Doak, Assistant in Ophthalmology, Vanderbilt University, has devised a test for vertical imbalances that not only detects and measures the error, but is also in itself a proof test. By this test the kind of error is at once detected, but its quantity is not known until the proof feature has been applied. The delicacy of the test is shown by an apparent doubling of the quantity of the error. This delicacy makes it dangerous only when the operator forgets that the apparent error is twice that of the real error. For making this test the monocular phorometer must be placed before one eye, and in the cell next to the eye must be placed either the 10° or 6° prism, base toward the nose. The controlling screw must be vertical, and the index, at the beginning, should stand at zero. The instrument must be level. The patient must hold before the other eye a double prism in such position as to make the test object (white spot on a black background) double for that eye, the one directly above the other, and the two should be 12° apart—that is, each of the double prisms should be 6°. With the double prism thus adjusted, these two spots

must be seen by *indirect* vision, while the single spot seen by the other eye should be observed by *direct* vision. Because of the displacing prism behind the phorometer, the single object will not be in line with the other two; and when it is seen by direct vision, the other eye will be so turned that the vertical imaginary line connecting the two false objects will fall to the nasal side of the fusion area, so that, as the test proceeds, there will be made no effort at fusion. The eye behind the double prism will be wholly off its guard. The moment the single object is fixed, the patient can usually say whether or not it would be halfway between the other two objects if it were in line with them. If the middle object is seen nearer the lower, that eye is hyperphoric; if nearer the upper, it is cataphoric. The proof feature of the test results from the use of the rotary prism. When the screw is turned so as to carry the index upward, the patient is asked to speak the moment the single object is in a horizontal line with the upper of the two false objects. The extent of the rotation is noted, after which the rotary prism is again made neutral. The next step is to carry the index of the rotary prism downward until the patient says that the single object is in a horizontal line with the lower of the two false objects. The extent of downward rotation is now noted. If the two arcs traversed by the index are equal, there is undoubtedly

vertical orthophoria of this eye. If the lower arc is 5° and the upper arc is 7°, this eye is certainly hyperphoric—not to the extent of the difference between these two arcs, which would be 2°, but only half this amount—viz., 1°. If the upper arc is 5° and the lower arc is 7°, there is cataphoria—not of 2°, but of 1°. The reason for saying that the real vertical error is only one-half of the apparent error is clear. Since each of the double prisms is 6°, the double objects seen through them, when the base-line is in the extended horizontal plane of the head, are 12° apart. The extended horizontal plane of the head cuts the imaginary line connecting the two false objects at the midway point—6° from each. If the displaced object seen by direct vision with the other eye is in this plane, it would have to be carried up or down by the rotary prism just 6° to be placed in a horizontal line with the one or the other of the false objects, hence the eye would be orthophoric vertically. If the true object is 1° below the extended horizontal plane of the head, it will have to be carried downward by the rotary prism only 5° to be placed in a horizontal line with the lower object, while it would have to be carried upward 7° to stand in a horizontal line with the upper object. Thus it is clear that the hyperphoria shown by this test is one-half the difference between the arcs traversed by the index of the phorometer in placing the true object in a

horizontal line first with the one false object and then with the other, the index each time starting from zero. Throughout the entire test the single object must be fixed. Although this test is in a sense binocular, it is probably better than any other test for two reasons: (a) It doubles the real error, so that a small error will be less likely to be overlooked; (b) this test proves itself.

The eye under the Doak test is the one behind the rotary prism. Both eyes should be subjected to the same test.

The duction and version power of the superior and inferior recti of both eyes must be taken in order to determine whether the hyperphoria and cataphoria are sthenic or asthenic, for on this knowlege must depend the treatment of the case.

If the superduction is less than 3° and the superversion is 33° or less, the hyperphoria is asthenic; if subduction is less than 3° and sub-version is below 50°, the cataphoria is asthenic. If superduction is more than 3° and superversion is greater than 33°, the hyperphoria is sthenic; if sub-duction is more than 3° and sub-version is greater than 50°, the cataphoria is sthenic.

Complications.—Focal errors do not complicate vertical heterophorias, except in cases in which there is pseudo-esophoria or pseudo-exophoria with too high or too low attachments of the lateral recti muscles. A

vertical error thus caused is pseudo in character and is cured, as is also the lateral pseudo-error, by correction of the focal errors.

The only complication that must always be thought of in the study of hyperphoria and cataphoria is cyclophoria; for by this complication is determined the treatment, surgical or otherwise, of these errors. How to find and measure this all-important complication will be set forth in the next chapter. If a hyperphoria is only complicated by esophoria or exophoria or by any focal error, all these troubles must be treated as if they existed alone.

Symptoms.

Any and all of the symptoms mentioned in the chapter on heterophoria may be caused by vertical imbalance. There is no facial expression that can be dignified as diagnostic of hyperphoria and cataphoria. There are poses of the head peculiar to both double hyperphoria and double cataphoria. High-headedness is a symptom of double hyperphoria when the inferior obliques cause the error, and is just as certainly a sign of double cataphoria when the inferior recti are the cause of the error. The most favorable position of the eyes for effective action of weak superior obliques and weak superior recti under a corrective nerve impulse is a depression of the visual axes below the extended horizontal plane of the

head, or (what is the same thing) elevation of the extended horizontal plane of the head.

The downcast look is a sign of double hyperphoria when the error is caused by the superior recti, and of double cataphoria when the error is caused by the superior obliques.

The most favorable position of the eyes for effective action of weak inferior obliques and weak inferior recti, under a corrective nervous impulse, is an elevation of the visual axes above the extended horizontal plane of the head, or (what is equal to it) a depression of the horizontal plane of the head.

A tilting of the head toward one shoulder or the other occurs only in cases in which there is a hyperphoria of one eye and a cataphoria of the other, complicated by either plus or minus cyclophoria of both eyes, and never in simple cases of hyperphoria. The hyperphoria and cataphoria are not the cause of the tilting of the head; the cause is the complicating cyclophoria. If the complication is plus cyclophoria, the head will be tilted toward the cataphoric side. In a case of this kind, tilting the head elevates the hyperphoric eye and depresses the cataphoric eye; so that to fix an object that would be in the extended horizontal plane of the head, if the head were erect, makes it necessary that the visual axis of the eye that is higher shall be depressed and that the

visual axis of the eye that is lower shall be elevated, so as to make them intersect at the object. Depression of the visual axis of the hyperphoric eye places the eye in such a position (elevated posterior pole) as to give to the superior oblique, under the whole of the stimulus of the sixth conjugate innervation, its greatest torsioning power, which would enable it easily to parallel the vertical axis of the eye with the now-inclined median plane of the head. The hyperphoria in such a case is due largely to the inferior oblique, and the plus cyclophoria is wholly caused by it. The elevated posterior pole of the eye, made necessary by the tilting of the head, places the inferior oblique at a disadvantage to the weak superior oblique; hence, the greater ease with which both the hyperphoria and the plus cyclophoria are counteracted.

The cataphoria of the other eye must be caused by the inferior rectus, and the same muscle most probably causes the whole of the plus cyclophoria of this eye. The corrective stimulus most likely comes from the first conjugate innervation center and is wholly expended on the superior rectus of the cataphoric eye (none of it is needed for the superior rectus of the hyperphoric eye), enabling it to counteract both the cataphoria and the plus cyclophoria. Its action is not favored by position. A corrective stimulus sent to the superior oblique

would lessen the cyclophoria, but increase the cataphoria; therefore it is reasonable to conclude that none is sent to it.

In a case of hyperphoria of one eye and cataphoria of the other, complicated by a minus cyclophoria, the head is tilted toward the hyperphoric side. The cataphoric eye is elevated, the hyperphoric eye is depressed, by this position of the head; so that the visual axis of the higher eye must be depressed and that of the lower eye must be elevated, so as to intersect at a point that would be in the extended horizontal plane of the head, if it were erect. In this case the hyperphoria and minus cyclophoria must be due to the superior rectus of that eye, while the cataphoria and the minus cyclophoria of the other eye must be due to its superior oblique. The corrective impulse of the hyperphoria must be sent to the inferior rectus which is favored in its action by the necessary elevated position of its visual axis. It must also receive nearly the whole of the impulse that comes from the second conjugate innervation center; for the inferior rectus of the other eye needs but little, if any, of it. Thus are counteracted both the hyperphoria and the minus cyclophoria.

The cataphoria and the minus cyclophoria of the other eye are counteracted by a corrective nervous impulse that is sent to its inferior oblique whose action is not favored

by the position that this eye must assume—an elevated posterior pole.

From what has been said above it will be observed that the tilting of the head toward the cataphoric side when there is plus cyclophoria, and toward the hyperphoric side when there is minus cyclophoria, is favorable only to the muscle that must correct the double error of the hyperphoric eye, thus showing that the depressor muscles are in greater need of the help that comes from posing. The tilting is really unfavorable to the muscle that must correct the double error of the cataphoric eye. It may be that a nervous impulse gets a readier response, in unfavorable positions of the head, from the muscles that elevate the eyes than from those that depress them. It is well known that when the eyes are closed in sleep, or even in meditation, they turn slightly up; and the same is true under anesthesia that is not profound. This peculiar endowment of the supervertors seems to be necessary in order that the cornea may be carried instantly, for protection, into the position of greatest security.

It is doubtful if there is a symptom or sign, other than the posing of the head, that is peculiar to vertical imbalance. Excessive secretion of tears may be associated, in some unaccountable way, with hyperphoria and cataphoria.

Treatment.

Vertical imbalance associated with pseudo-esophoria or pseudo-exophoria may be dependent on it; and if so, it should be relieved by the same lenses that cure the lateral pseudo error.

Since a double hyperphoria may be caused by abnormal action of the inferior obliques, excited by oblique astigmatism with the meridians of greatest curvature converging above, and since double cataphoria may be caused by abnormal action of the superior obliques, excited by oblique astigmatism with the meridians of greatest curvature diverging above, these errors may be relieved, in such cases, by the correcting plus or minus cylinders.

Inherent vertical imbalance is made neither better nor worse by the lenses that correct focal errors. These must be treated by exercise, by prisms in positions of rest, or by operations.

Exercise.

Double hyperphoria may be treated by exercise of the inferior recti, which is best done by looking straight ahead and then down to an object on the floor five or six feet distant, then again straight ahead and then down again, repeating this at regular intervals of three seconds. This straight-forward-to-floor exercise should be stopped short of fatigue, and should not be

continued longer than ten minutes. One exercise a day is sufficient.

The exercise for double cataphoria is straight-forward-to-ceiling exercise, and should be carried out in the same manner as the straight-forward-to-floor exercise.

Prism exercise alone is applicable when there is hyperphoria of one eye and cataphoria of the other. The

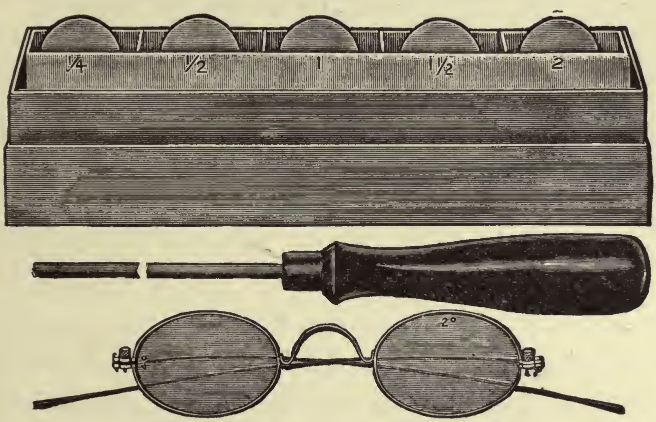

Fig. 24.

prisms with which to begin the exercise should be weak, and gradually stronger ones should be used, but they should never be stronger than 2°. Except for the cost, the prisms should be in pairs of equal strength. The hyperphoric set shown in the accompanying cut (Fig. 24) consists of five prisms, as follows: $\frac{1}{4}°$, $\frac{1}{2}°$, 1°, $1\frac{1}{2}°$, and 2°.

The apex of the prism must point toward the muscle to be exercised—that is, it must be down for the hyperphoric eye and up for the cataphoric eye. When the prisms are of unequal strength, after three or four days' use they should be transferred and the exercise continued for three or four days longer. Now the weaker prism ($\frac{1}{4}°$) may be removed and the 1° prism put in its place. At the proper time the $\frac{1}{2}°$ prism and the 1° prism should be transferred, and the exercise should be continued with them for three days, when the $\frac{1}{2}°$ prism should be removed and the $1\frac{1}{2}°$ prism put in its place. The substitutions should thus continue until the $1\frac{1}{2}°$ and 2° prisms are in the frames. The exercise should be continued indefinitely with these prisms, transferring them from side to side at regular intervals, always placing apex down for the hyperphoric eye and apex up for the cataphoric eye. The muscles should be exercised rhythmically by lowering and raising the frames containing the prisms, at intervals of three seconds. The exercise should be stopped short of fatigue and need not be continued longer than ten minutes. Once a day is sufficiently often to exercise. The object of fixation while exercising should be twenty feet distant, and should be sufficiently sharp in outline and bright to excite ready response of the muscles for the purpose of fusing the two displaced images.

Relieving prisms for vertical imbalance are often of great use. Hyperphoria and cataphoria, uncomplicated, of less than $1\frac{1}{2}°$, should be relieved, if possible, either by exercise or by rest prisms. Cases in which these errors are as great as 2° or greater, whether complicated or not, may obtain some relief from non-surgical means, but cannot be cured short of operations. If the vertical errors are as low as 1° and there is a complicating cyclophoria, surgery is the thing indicated.

The sub-ducting muscles stand in greater need of rest prisms than do the superducting muscles, for the reason given in the study of the posing of the head, in that part of this chapter devoted to symptoms. If there were no other reason, it would be good practice in many cases, not complicated with minus cyclophoria, to apply the whole prismatic correction to the hyperphoric eye; and certainly this should be the practice if there is a complicating plus cyclophoria, however small in quantity. The superior rectus raising the eye to overcome the effect of the prism, in the interest of binocular single vision, torts it in, thus aiding the superior oblique to parallel the vertical axis of the eye with the median plane of the head.

In the few cases of hyperphoria and cataphoria that are complicated by minus cyclophoria, the whole of the

prismatic effect should be applied to the cataphoric eye. The prism, with its base up before this eye, calls into action the inferior rectus in the interest of fusion; and thus aid is given the inferior oblique in its efforts to parallel the vertical axis of the eye with the median plane of the head.

Those cases of hyperphoria and cataphoria that are not complicated by cyclophoria will be given more comfort if the greater part (two-thirds) of prismatic effect is applied to the hyperphoric eye, than would be given if this rule were reversed, or even if the effect were equally divided between the two eyes.

If the rules given above are observed, many cases will take even a full correction of the hyperphoria, and not less than half the full correction should ever be given. The purpose may be attained either by prisms or lenses rendered prismatic by decentration.

Double cataphoria that causes the patient to hold his head too high should be given prisms or prismatic lenses, bases up, so as to let them assume a more nearly normal position of the head, provided there is no complicating plus cyclophoria. The effect should be equally divided between the two eyes.

Patients suffering from double hyperphoria should be given prisms or prismatic lenses, bases down, except when there is a complicating minus cyclophoria. These

would enable the patient to carry his head comfortably in a more nearly erect position.

Hyperphoria, single or double; cataphoria, single or double; and hyperphoria of one eye and cataphoria of the other, caused by malformation of the orbits, should always be given full prismatic correction of the error found in each eye.

Operative Treatment.

A double hyperphoria that cannot be relieved by prisms or by straight-forward-to-floor exercise, to the extent of enabling the patient to carry his head erect, instead of downcast, should be subjected to a partial tenotomy of both superior recti. If there is no complicating minus cyclophoria, the tenotomies should be central; but should this complication exist—as it would if the superior recti are wholly at fault—the tenotomies should be peripheral, including only the temporal fibers. Should there be a complicating plus cyclophoria—as there would be if the inferior obliques were wholly to blame for the double hyperphoria—peripheral tenotomies of the superior recti should be done, including only the nasal fibers. In either case, the operative effect should be equally divided between the two muscles.

A double cataphoria does not so urgently demand operations, for high-headedness is not so objectionable as

the downcast look. The position of the head in double cataphoria is more favorable to the respiratory act than is the position caused by double hyperphoria—another reason why operative interference is less urgent in double cataphoria. The lid pressure—pressure of the upper lids against the globe—is much less in double cataphoria than in double hyperphoria. Since great lid pressure is probably more favorable to the retention and development of germs, especially the trachoma germ, as suggested by Stevens, there is an additional reason for operating more frequently for double hyperphoria than for double cataphoria.

Straight-forward-to-ceiling exercise, or prisms with their bases up, should always be tried in cases of double cataphoria; but should these fail to enable the patient to carry his head in the natural, erect position, a partial tenotomy of both inferior recti should be done, and these operations should be central, unless there is a complicating cyclophoria. In cases in which there is a complicating plus cyclophoria—as there would be if the double cataphoria is caused by the inferior recti—peripheral tenotomies should be done, including only the temporal fibers. In those cases complicated by a minus cyclophoria, the superior obliques are the cause; but since these muscles cannot be, or ought not to be, operated upon, peripheral tenotomies of the inferior recti, including only

the nasal fibers, should be done. The operative effect should be equally divided between the two inferior recti. Great care should be exercised, in operating for double cataphoria, not to convert it into a double hyperphoria. Operations on the inferior recti are as easily done as on the superior recti.

Since double cataphoria is preferable to double hyperphoria, there is good reason for always operating first on the superior rectus of the hyperphoric eye in cases in which there is hyperphoria of one eye and cataphoria of the other. While the tenotomy should never be complete, it should be more extensive when done with the view of lowering the hyperphoric eye than when done for elevating the cataphoric eye; hence, the reason for doing the first operation as set forth in the beginning of this paragraph. After the first operation, the remaining imbalance must be corrected by a partial tenotomy of the inferior rectus of the cataphoric eye. As in the lateral heterophorias, so in the vertical errors, tenotomies are indicated only in the sthenic forms. A superduction of 3° or less should never be diminished by lessening the tension of a superior rectus; and a sub-duction of 3° or less likewise contraindicates a tenotomy. An asthenic hyperphoria and cataphoria demands, first of all, a shortening of the inferior rectus of the hyperphoric eye, by means of which the greater part of the effect should be

accomplished, the remaining part of the imbalance to be corrected later by a shortening of the superior rectus of the cataphoric eye.

In all cases of hyperphoria and cataphoria, uncomplicated by cyclophoria, the operations, if partial tenotomies, should be central; and if shortenings, should be straight-forward, so as not to change the plane of rotation. The complication of plus cyclophoria calls for a peripheral tenotomy of the superior rectus of the hyperphoric eye, including only the nasal fibers, and a peripheral tenotomy of the inferior rectus of the cataphoric eye, including only the temporal fibers. These two operations should be as nearly coextensive as possible, because of the desire to correct the cyclophoria. Should a case of this character be asthenic, the inferior rectus of the hyperphoric eye should be shortened in such a way as to carry its plane of rotation farther in, and the superior rectus of the cataphoric eye should be so shortened as to carry its plane of rotation farther toward the temple. The operative effect should be equally divided between the two muscles.

The complication of minus cyclophoria, which is rare, indicates a peripheral tenotomy of the superior rectus of the hyperphoric eye, including only its temporal fibers, so as to carry its plane of rotation farther toward the nose, and a like operation on the nasal fibers of the in-

ferior rectus of the cataphoric eye, so as to carry its plane of rotation farther toward the temple. An equal effect should be attained by these two operations. If a case of this character should be asthenic, the inferior rectus of the hyperphoric eye shonld be so shortened as to carry its plane of rotation farther toward the temple, while the superior rectus of the cataphoric eye should be so shortened as to carry its plane of rotation farther toward the nose.

The methods of doing these operations are set forth in the chapter on heterophoria, and the after-treatment is also described in that chapter.

CHAPTER VII.

CYCLOPHORIA.

CYCLOPHORIA is the tendency of the vertical axes of the eyes to lose parallelism with the median plane of the head. In the interest of binocular single vision this parallelism must be maintained by the oblique muscles, except in cases of oblique astigmatism. For this purpose there are four conjugate innervation brain-centers: (1) The sixth conjugate center sends an impulse to the two superior obliques to prevent divergence of the vertical axes when the point of view is in the extended median plane of the head, but below the extended horizontal plane; (2) the seventh conjugate center sends an impulse to the two inferior obliques to prevent convergence of the vertical axes when there is to be cardinal fixation above the horizontal plane; (3) the eighth conjugate center sends an impulse to the superior oblique of the right eye and inferior oblique of the left eye to prevent torsion when the point of fixation is obliquely up and to the right, or down and to the left; and (4) the ninth conjugate center sends an impulse to the superior oblique of the left eye and inferior oblique of the right eye to pre-

vent torsion when the point of fixation is up and to the left, or down and to the right. Under the influence of one or another of these conjugate centers, parallelism of the vertical axes of the eyes with the median plane of the head is maintained, regardless of the direction of the point of fixation. In a normal condition of all the extrinsic ocular muscles, the obliques accomplish this purpose with ease. Whenever conditions are such as to make it difficult for the obliques to maintain this parallelism, except when under an excessive nervous tension, there is cyclophoria.

When this condition was first described in the Archives of Ophthalmology, in its issue of January, 1891, the name given it was "insufficiency of the obliques," which was not inapt; for whatever may be the chief cause or causes of this error, the obliques are *insufficient* for the work of easily keeping the vertical axes of the eyes parallel with the median plane of the head. In 1893, in conformity with the terminology introduced by Stevens, the term "cyclophoria" was coined by Price. Plus cyclophoria means that the vertical axes of the eyes have a tendency from the median plane of the head; minus cyclophoria is a tendency of these axes toward the median plane. For the same conditions Maddox uses the terms "plus torsion" and "minus torsion;" and Stevens, "plus declination" and "minus declination." Either of these terms

would be as good as those coined by Price, except for the desirableness of uniformity in terminology.

While cyclophoria is most important as it pertains to the two eyes in their efforts to maintain binocular single vision, it is, nevertheless, a factor for disturbance in monocular vision. In order that the law of direction may not be interfered with, in vision with one eye, its vertical axis must always be parallel with the median plane of the head; and, necessarily, its transverse axis must always lie in the horizontal plane of the head or be parallel with it.

There are two kinds of cyclophoria—viz., symmetrical and non-symmetrical. Symmetrical cyclophoria is either plus or minus for both eyes; non-symmetrical cyclophoria is plus for one eye and minus for the other. Rarely there may be a plus or minus cyclophoria for one eye, while the obliques of the other perform their work easily. Plus cyclophoria is by far more common than minus cyclophoria.

Causes of Cyclophoria.—The cause may be wholly in the obliques. The nearer the attachment of an oblique muscle is to the equator, the greater is its torsioning power; while attachment of an oblique nearer the posterior pole of the eye gives it less torsioning power. Attachment of both inferior obliques nearer the equator than that of the superior obliques, would give a plus

cyclophoria, the muscles themselves being normal in development. When the superior obliques are attached nearer the equator than are the inferior obliques, a minus cyclophoria would result. Granting that the attachments are correct, hyper-development of the inferior obliques or subnormal development of the superior obliques would give a plus cyclophoria; while hyper-development of the superior obliques or subnormal development of the inferior obliques would cause a minus cyclophoria. This presupposes that the innervations are normal.

Hyper-development of the seventh conjugate innervation center, or subnormal development of the sixth, would cause a plus cyclophoria; while hyper-development of the sixth or subnormal development of the seventh conjugate center, would cause a minus cyclophoria. This presupposes that the muscles themselves are normal in both structure and attachment. In either case the plus cyclophoria would be complicated by a double hyperphoria, and the minus cyclophoria would be complicated by a double cataphoria.

A too high attachment of the interni or a too low attachment of the externi would cause a minus cyclophoria, while a too low attachment of the interni or a too high attachment of the externi would cause a plus cyclophoria. When there is a normal attachment of the interni, there can result from their action no cyclophoria.

The superior and inferior recti constitute the only remaining source of symmetrical cyclophoria. When these muscles are normal in structure and attachment, there can be no cyclophoria resulting from their action. A double hyperphoria due to hyper-development of the superior recti or subnormal development of the inferior recti, gives a minus cyclophoria; while hyper-developed inferior recti or subnormally developed superior recti, in causing double cataphoria, also cause plus cyclophoria.

Non-symmetrical cyclophoria is a tendency to parallel deviation of the vertical axes of the eyes, being plus for one eye and minus for the other. This tendency may be to the right or to the left. If this kind of tendency should become a turning, diplopia would not result, but there would be interference with the law of direction. Because of this interference the weaker obliques (superior of one eye and inferior of the other) are kept in a state of nervous tension, that they may keep the vertical axes of the eyes parallel with the median plane of the head. The corrective impulse comes from the eighth conjugate center when the tendency of the vertical axes is toward the right, and from the ninth center when the tendency is toward the left. When the tendency is toward the right, rotation of the eyes obliquely up and to the right, or down and to the left, is more dif-

ficult than rotation up and to the left, or down and to the right; and *vice versa*, when the tendency is toward the left.

The obliques may cause this condition. To do so the superior oblique of one eye must be too strong for its inferior oblique, or the former must be attached nearer the equator than the latter; while the inferior oblique of the other eye is either stronger than its superior oblique or is attached nearer the equator. In such a case there would be not only parallel cyclophoria, but there would be also a cataphoria of the one eye and a hyperphoria of the other. Parallel cyclophoria can be caused by the interni when one is attached in greater part above the transverse plane of its eye, while the other is attached in greater part below this plane. There would also result a hyperphoria of the one eye and a cataphoria of the other. Faulty attachment of the externi, the one too high and the other too low, would cause parallel cyclophoria. In such a case there would also be a hyperphoria of one eye and a cataphoria of the other. When hyperphoria of one eye is caused by a too strong superior rectus and cataphoria of the other is caused by a too powerful inferior rectus, parallel cyclophoria will also result, the tendency being to the right when there is left hyperphoria and to the left when there is right hyperphoria.

Tests.

Cyclophoria was first discovered in 1890 by means of a Maddox double prism which was being used for determining an imbalance of the lateral recti. The patient was asked if the middle candle was in a *vertical* line with the upper and lower candles. She stated that the lower candle was not directly under the upper one, although the axis of the double prism was vertical, or so judged by the eye of the operator. The axis of the prism had to be tilted 5° or more toward the temple before the patient claimed that the upper and lower candles were in a vertical line. This showed clearly that the vertical retinal meridian was inclined toward the temple and to a greater extent than Helmholtz had taught as normal. At once a line was drawn across a card and held before the patient. She saw two lines with the eye before which the double prism was held, and these lines were parallel. The other eye was then uncovered, when she saw a third line between the other two lines, but not parallel with them. The middle line was seen by the left eye, and it was seen inclined down to the right. Other cases were investigated, about twenty-five per cent of them showing the same error found in the first patient, which was plus cyclophoria. The first publication was made in the Archives of Ophthalmology, Vol. XX., No. 1, page 105. This paper was gloomy in that it presented no

prospect of either prevention or cure. From the time of the discovery of cyclophoria, in 1890, up to May, 1892, many cases had been found, but none of them had been treated; nor was it thought possible, up to this time, that any curative measure would ever be devised. On May 17, 1892, the thought of developing weak oblique muscles by exercising them with cylinders first presented itself. This thought was put into practice at once, and the results were gratifying. This led to the presentation of a second paper which was read before the Section of Ophthalmology of the American Medical Association at the Detroit meeting, in June, 1892.

The double prism will always show cyclophoria when the test object is a horizontal line. The kind of cyclophoria—whether plus or minus—is easily ascertained in this way, but its quantity cannot be measured. Substituting a dot for the line, the error may be measured by revolving the double prism until the two dots seen through the prism are in a vertical line. The extent of inclination of the axis of the prism would be equal to the amount of the cyclophoria. In using the double prism for this measurement test of cyclophoria, the operator must be careful to have the axis of the prism vertical in the beginning and note its inclination at the end of the test. He need not be so careful to have the patient's head erect, for the result will be the same whether the

head is erect or inclined. However, since tests of some of the eye muscles require that the head shall be erect, it is better to have it thus in all tests.

The cut used to illustrate the first paper is reproduced here, together with the descriptive text:

"Place a double prism, axis vertical, before one eye, the other for the moment being covered, and ask the patient to look at a horizontal line on a card held sixteen inches away. The effect of the double prism (each 6°) is to make the line appear to be two, each parallel with the other. The other eye is now uncovered, and a third line is seen between the other two, with which it should be perfectly parallel.

"While a change of the position of the axis of the double prism, from the vertical toward the horizontal, will alter the distance between the lines, their direction will be unchanged—hence, no loss of parallelism. This fact admits of a little carelessness in the placing of the prism in the trial frames, though the axis should be vertical, so as to give the maximum distance between the two extreme lines.

"If there is a want of harmony on the part of the oblique muscles, this test will show it at once in a want of parallelism of the middle line with the two other lines, the right end of the middle line pointing toward the bottom line and the left end toward the top line, or

vice versa, depending on the nature of the individual case.

"Consider the eye before which no prism is held as the one under test. With the double prism before the right eye, the patient is asked about the position and

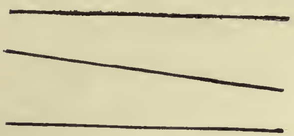

Fig. 25.

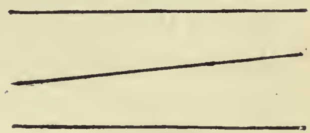

Fig. 26.

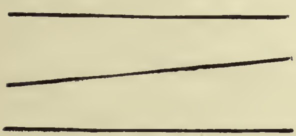

Fig. 27.

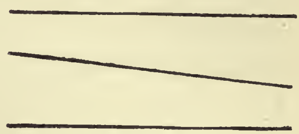

Fig. 28.

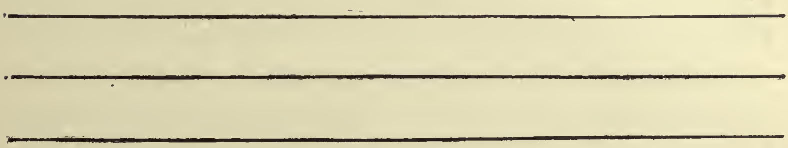

Fig. 29.

the direction of the middle line. It may be nearer the bottom line, thus showing left hyperphoria; or, again, it may extend farther to the right than the other two, and not so far to the left, thus showing exophoria; or *vice versa*, showing esophoria.

"If the right ends of the middle and bottom lines converge while the left ends diverge, the superior oblique of the left eye is at once shown to be in a state of under-action. Fig. 25 represents such a test of the left eye; Fig. 26 shows a test of the left eye when the inferior oblique is the too weak muscle; Fig. 27 represents a test of the right eye, the loss of the parallelism between the lines being due to under-action of its superior oblique; Fig. 28, the same condition of the inferior oblique of the right eye; Fig. 29 represents a test of both eyes when there is perfect equilibrium of the oblique muscles."

The single prism of 6°, with its base up or down before one eye, the test object being a horizontal line on a blackboard at twenty feet distance, or on a card at the reading distance, will double the line. If the two are not parallel, there is cyclophoria. The false line inclined toward the opposite side shows plus cyclophoria; the same line inclined toward the corresponding side shows minus cyclophoria. The quantity of the cyclophoria cannot be measured with the single prism by substituting a dot for the line, as in the use of the double prism.

The rotary prism of either the Wilson or the monocular phorometer can easily show the existence of cyclophoria, or its absence. As with other prisms, the test object is a line. The rotary prism is adjusted for taking

sub-duction and superduction. When it is rotated up or down beyond the point of possible fusion, the line becomes double. If they converge at one end or the other, there is cyclophoria—plus if the false line is inclined toward the opposite side, minus if it is inclined toward the same side. Rotating the prism slowly so as to carry the index toward zero, the two lines fuse, first at one end and then quickly fuse throughout. The rotary prism cannot possibly measure the amount of cyclophoria.

The Stevens clinoscope both detects and measures any form of cyclophoria. The opaque discs with a single pin, with the head in the center, drawn on each, should be placed so that the point may be up for one eye and down for the other. Each pin should be vertical, and the instrument should be so adjusted as to allow easy fusion of the heads of the pins. When the two discs appear as one, the two pins should be the vertical diameter of the fused disc. If the one pin is a radius pointing obliquely in one direction and the other is a radius pointing obliquely in the other direction (one toward the right and the other toward the left, making an oblique diameter), there is plus cyclophoria of one eye and minus cyclophoria of the other. If the upper pin is seen by the left eye and the lower pin is seen by the right eye, the two pins pointing to the right would show plus cyclophoria; while minus cyclophoria would be shown by the

two pins pointing to the left. If the top pin is vertical and the bottom one points to the right, there is plus cyclophoria of the right eye alone; or, if the bottom pin points to the left, while the top one is vertical, there is minus cyclophoria of the right eye alone. When both pins are oblique, the tubes to which the discs are fastened should be revolved until the two pins are vertical, forming apparently the vertical diameter of the fused disc. The index connected with each tube will point to the mark on the scale indicating the quantity of the error for each eye.

The errors of the obliques could be detected with equal ease and measured with as much exactness, if the discs were placed so that the pins would be horizontal, the one seen by the left eye pointing to the left and the one seen by the right eye pointing to the right, their heads being fused. To eyes whose oblique muscles are perfectly balanced the pins would appear as the horizontal diameter of the fused disc. If the two pins appear to point downward, there is minus cyclophoria; if they appear to point upward, there is plus cyclophoria. If the left pin points downward, while the right pin points upward, there is minus cyclophoria of the left eye and plus cyclophoria of the right eye (parallel cyclophoria). In either case, rotation of the two tubes until the pins appear to be horizontal, constituting the apparent horizontal diameter of the fused disc, measures the error.

The cyclo-phorometer will also detect and measure both symmetrical and non-symmetrical cyclophoria. The instrument must be perfectly level, and the index of each triple rod must stand at zero. The 5° prism, base up, must be placed in the slot behind one rod, while a red glass may be put in the slot behind the other rod. The test object must be a candle, gas jet, or small electric light. The red streak above and the yellow streak below must be made even by the regulating screw. To perfectly balanced eyes these streaks would appear parallel. If the red streak is seen by the right eye and the two converge at the left, there is plus cyclophoria; if they converge at the right, there is minus cyclophoria. If they appear parallel, but inclined, there is plus cyclophoria of one eye and minus cyclophoria of the other. If one is horizontal and the other is inclined, there is cyclophoria of one eye alone. The disc containing the rods should be turned until both streaks are perfectly horizontal and, therefore, parallel. If the index of each stands in the nasal arc when the streaks are made to appear horizontal, there is plus cyclophoria; and if they stand in the temporal arcs, there is minus cyclophoria. The quantity of the error in each eye is measured by the arc traversed by the index and is shown on the scale. If only one rod is turned until the two streaks become parallel, but not horizontal, the quantity marked by the in-

dex is the sum of the cyclophoria of the two eyes. If there is parallel cyclophoria, the quantity is shown by revolving the two rods until the two streaks are horizontal.

Cyclo-duction can be taken either with the clinoscope or the cyclo-phorometer. If the clinoscope is used, the discs, with a diameter drawn across each, should be attached. They can be set with the diameters either vertical or horizontal. When vertical, revolving the tubes so that the lines shall deviate from each other above will put into action the inferior obliques. If only one tube is revolved, only one inferior oblique is called into action, while revolving both tubes will call into action both inferior obliques. The normal duction power of the obliques is not so well known as that of the recti. It is somewhere between 7° and 14° for one, and 22° or less, for both inferior obliques.

Revolving the tubes so that the lines converge above puts the superior obliques to the strength test. If only one tube is revolved, only one superior oblique is called on for a fusion effort; but if both are revolved, both eyes must be cyclo-ducted by the two superior obliques. The fusion power of the superior obliques is less than that of the inferior obliques, but how much less normally is not known. In plus cyclophoria, minus cyclo-duction is diminished and plus cyclo-duction is increased; while in

minus cyclophoria, plus cyclo-duction is less and minus cyclo-duction is greater. In taking either minus or plus cyclo-duction the revolution of the cylinders must be stopped the moment the lines begin to be seen separately. The index will point to the number indicating the extent of the fusion rotation.

Placing the discs so that the two diameters shall be horizontal, both plus and minus cyclo-duction can be taken as easily and accurately as, if not more accurately than, when these lines are vertical. Rotating the tubes so that these lines are made to point downward at their outer ends will call into fusion activity the two inferior obliques, while rotating them so that they shall point upward will excite into fusion activity the superior obliques.

When the cyclo-phorometer is used for measuring the fusion power of the obliques, the instrument should be adjusted as for testing for cyclophoria. As soon as the rods are so rotated that the one streak of light is directly under the other, both the displacing prism and the red glass should be removed. At once the two lines would be fused into one horizontal line. Revolving one rod so that the index shall move in the nasal arc puts to the test the inferior oblique of that eye; revolving both rods so that each index shall be in the nasal arc puts both inferior obliques to the test. When the two streaks

of light are well defined and exactly alike as to width and color, the plus cyclo-duction should be as great with this instrument as with the clinoscope.

Revolving the rods so that the index of each shall move in the temporal arc, excites into fusion activity both superior obliques. If one alone is to be tested, only the one rod should be revolved, the other being allowed to stand at zero. Thus plus and minus cyclo-duction should be taken in all cases of cyclophoria; and even when there is no cyclophoria, these should be taken and noted, so that a standard may be attained.

The first instrument for taking cyclo-duction was invented by Dr. C. H. Perry, of Oneida, N. Y., and for this purpose is but little, if at all, inferior to the clinoscope or the cyclo-phorometer. A description of this instrument and its use was published by the Ophthalmic Record, in its issue of November, 1895, in the inventor's own language. It reads as follows:

"Fig. 30 represents a stereoscopic card, to which are centrally pivoted two thin discs, each three inches in diameter, their centers being three inches apart in a horizontal line.

"These discs are mashed together at their point of contact by a single interlocking slot in each.

"The left disc is moved by a lever passing under the right, and is provided with an index, which shows, on a

graduated scale at the right-hand of the card, the number of degrees that each disc is rotated. Having equal diameters, and being geared together, they move synchronously equal distances, but in opposite directions.

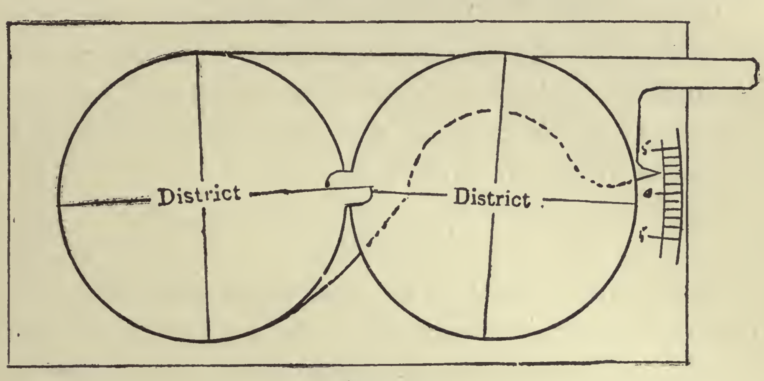

Fig. 30.

Horizontally over the center of each disc is printed a word, and vertically through each of said centers is drawn a line.

"When this apparatus is seen in a stereoscope and the discs are rotated by moving the lever, the two words will remain blended while each disc moves through an arc of about 5° (and much more in some subjects); and if attention is given to the perpendicular lines, they will appear as a single line during the rotation of about the same arc. If used with due care, this instrument gives a practically accurate measurement not only of the rela-

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tive, but of the absolute, power of rotation in each direction."

Cyclo-version is impossible, since voluntary rotation of the eyes around the visual axes cannot be accomplished.

In the study of the causes of cyclophoria, all of the complications have been considered. Under the head "Treatment" they will be referred to again, since the treatment, whether surgical or otherwise, is largely determined by these complications.

Symptoms.

Any one or several of the symptoms mentioned in the chapter on heterophoria may result from cyclophoria. Vertigo and nausea are more commonly found associated with cyclophoria than with any other form of heterophoria. As already shown in the study of hyperphoria and cataphoria, it is plus cyclophoria that causes the tilting of the head toward the cataphoric side, and minus cyclophoria that causes the tilting of the head toward the hyperphoric side.

Symmetrical plus cyclophoria associated with double hyperphoria causes high-headedness, for the reason that the superior obliques can more easily counteract a plus cyclophoria when the visual axes are depressed below the extended horizontal plane of the head. Symmetrical minus cyclophoria with double cataphoria causes the pa-

tient to carry his head thrown forward, giving a downcast appearance, because, in this position, the inferior oblique can counteract more easily the minus cyclophoria.

TREATMENT.

Rest cylinders, exercise cylinders, and operations on the recti constitute the means for curing cyclophoria. When cyclophoria was discovered, in 1890, a cure was thought to be impossible. In 1892 the first case was treated with exercise cylinders. In 1888 the late Dr. H. Culbertson, in a paper read by him before the Section of Ophthalmology of the American Medical Association, embodied the idea of the usefulness of cylinders not only for the correction of astigmatism, but also for giving rest to weak oblique muscles. The title of that paper was "Binocular Astigmatism," and in it he advocated rotating cylinders out of the positions indicated in the monocular test, so that distortions of objects might be overcome. He claimed, and correctly so, that many of his patients obtained comfort from this procedure. He claimed no basis for this practice other than empiricism, whereas there is a scientific basis for it, which will be given farther on.

The germ of the idea of operating on the recti so as to help weak obliques is embodied in language found in the Ophthalmic Record, in its issue of March, 1893. These

are the words: "*In doing advancement operations on the recti muscles, one of the chief dangers is turning the eyeball on its antero-posterior diameter so as to throw unbearable strain on either the superior or inferior oblique muscles.*" At once it should have occurred to the author of the quotation just made that, naturally, the recti might be so attached as to do the very same thing—that is, develop a cyclophoria.

While in attendance on the first Pan-American Medical Congress, Dr. Swan M. Burnett suggested to the author that the superior and inferior recti might have such a scleral attachment as to throw an undue amount of strain on the obliques. On hearing this statement the author made this suggestion: "*If you are correct, some cases of insufficiency of the obliques can be cured by dividing the offending fibers of the inferior* (*or superior*) *recti.*" This was published in the first edition of "New Truths in Ophthalmology" (1893), page 41.

REST CYLINDERS.—These can be given for either plus or minus cyclophoria even when there is no astigmatism to be corrected. The objection to this practice is that, while they give rest to the weak obliques, they, at the same time, make images on the retinas less distinct. It is the distorting, or it would probably be better to say "the displacing," of images that gives rest to the weaker obliques. It is no longer denied that, in astigmatism,

all lines not parallel with one or the other of the two principal meridians have their images displaced toward the meridian of greatest curvature. To fuse such displaced images (displaced in opposite directions) there must be cyclotropia, just as there must be esotropia in order to fuse images that are thrown to the temporal side of the maculas by prisms with their bases out. The law of corresponding retinal points, which is supreme, compels the cyclotropia of oblique astigmatism, notwithstanding it must interfere with the law of direction, in that the vertical axes of the eyes are made either to converge or diverge above. Artificial oblique astigmatism produces the same changes in images of vertical and horizontal lines as does natural oblique astigmatism. When there is plus cyclophoria, natural oblique astigmatism of 1 or 2 D, with the meridians of greatest curvature converging above, is often attended by more comfort, because of the rest it gives to the superior obliques, than the correcting cylinders would give; for when the correction is given, the image of every line in space is in a plane with the line itself, and to fuse these images the weak superior obliques must parallel the vertical axes of the eyes with the median plane of the head. To do this their normal tension must be supplemented by a nervous tension which they poorly bear. What natural astigmatism will do, artificial astigmatism

will accomplish. Only weak cylinders should be used for non-astigmatics, with the view of resting weak oblique muscles. More than 1 D, whether the axis be made to incline little or much, would blur objects unnecessarily. Cylinders of .50 D are usually strong enough, especially when their axes are made to incline far toward maximum points, in the proper arcs. For plus cyclophoria the arc of distortion for plus cylinders is the lower nasal arc; for minus cylinders, the lower temporal arc. The maximum distortion by the cylinder is accomplished when its axis stands at 45° from the vertical. For minus cyclophoria the arc of distortion for plus cylinders is the lower temporal arc; for minus cylinders, the lower nasal arc. For non-astigmatics each arc of distortion is 90°, the distortion or displacement gradually increasing as the axis of the cylinder is carried up to the midway point (45°) of the arc, and then gradually grows less as the axis is carried on toward the horizontal, at which point there can be no distortion. The most useful cylinder is a plus .50 D when there is esophoria as well as cyclophoria, or a minus .50 D when there are exophoria and cyclophoria. The quantity of the cyclophoria determines the location of the axes of the cylinders, but in no case need they be placed farther from the vertical than 45°, for this is the point where they accomplish the maximum distortion, thereby securing, for the

weak obliques, the greatest amount of rest. Given a case of plus cyclophoria that is also esophoric, but non-astigmatic, to obtain rest for the weak superior obliques a plus .50 D cylinder should be given for each eye, placing the axis of the right cylinder at some point between 90° and 135° or at the latter, while placing the axis of the left cylinder at some point between 90° and 45° or at the latter. These cylinders will give additional comfort to nearly all cases of this kind.

It is better, however, to cure these cases either by exercising the weak superior obliques or by operating on the interni.

If there is a hyperphoria of one eye and a cataphoria of the other, as well as plus cyclophoria, the rest cylinder should be applied only to the cataphoric eye. The inferior oblique, in torting this eye out for fusing images with the fellow eye, would also elevate the eye, counteracting the cataphoria. For a like reason, the rest cylinder should be applied only to the hyperphoric eye for the relief of minus cyclophoria. But it would be better practice to cure the plus cyclophoria by a marginal tenotomy (on nasal side) of the superior rectus of the hyperphoric eye, or by exercising both superior obliques.

Cylinders given for the correction of astigmatism, oblique or non-oblique, may be so placed as to give rest to weak superior obliques when there is plus cyclophoria,

or to weak inferior obliques when there is minus cyclophoria. If the astigmatism is vertical and hyperopic, the arc of distortion by the plus cylinder for the superior oblique is 90°, and that for the inferior oblique is also 90°, their sum being 180°; if the astigmatism is oblique, the meridian of greatest curvature of the right eye being at 60° and that of the left eye at 120°, the arc of distortion by the correcting cylinders for the superior obliques will be 30°, and that of the inferior obliques will be 150°, their sum being 180°. If the meridian of greatest curvature of the right eye is at 45°, and of the left eye at 135°, there is no arc of distortion for the superior obliques, but the arc of distortion for the inferior obliques is 180°. The center of the arc of distortion by plus cylinders for the superior obliques is at 45° in the lower temporal arcs, and for the inferior obliques is at 45° in the lower nasal arcs. This is reversed in the use of minus cylinders. This will be elucidated further in the chapter on cyclotropia.

From what has just been said, it will be understood that, when plus cylinders are used for correcting astigmatic errors, their axes must be turned from the point indicated by the astigmatism toward the center of the lower nasal arc for the relief of weak superior obliques in plus cyclophoria, and toward the center of the lower temporal arc for the relief of weak inferior obliques in

minus cyclophoria. The extent of the displacement of the axes depends both on the strength of the cylinders and the quantity of the cyclophoria. Rarely should this displacement be more than 5° if the cylinders are plus 1 D, or stronger; but weaker cylinders may be revolved much farther.

Culbertson displaced the axes of his cylinders with the view of correcting the appearance of slanting floors, leaning walls, and distorted figures, without any reference at all to the oblique muscles; but, after all, the benefit derived was from giving rest to the weak obliques. In vertical astigmatism, the cylinders do not cause the floor to slant or the wall to lean; and yet it is just as essential to displace the axes of the correcting cylinders in the proper arcs, when there is cyclophoria, as it is to displace the axes of cylinders correcting oblique astigmatism.

In 1894, Nettleship, and probably others on the staff of the Royal Ophthalmic Hospital, London, was in the habit of directing that the axes of cylinders should be placed at 90° or 180°, when accurate measurements showed that the two principal meridians were removed only a few degrees from these points. When asked why he did this, he said that some patients derived more comfort from the displaced cylinders. There was then present a female patient who could not wear her cylinders

thus displaced. Inquiry elicited the fact that she had been given plus cylinders—axes, 90°—for each eye, when the record showed that the meridian of greatest curvature of the right eye was at 100°, and of the left eye at 80°. These cylinders were displaced in the arcs of distortion for the superior obliques, which were evidently too weak to bear the consequent over-action. In that case, it would have been better to have displaced these axes farther from the vertical instead of to it.

Better than displacing the axes of correcting cylinders, so that they may give rest to the weak oblique muscles, is to make these muscles strong by exercise, or else correct the cyclophoria by operating on one or more of the recti.

Exercise of the Obliques.

This can be accomplished by the Perry cards (see Fig. 30) used in the stereoscope. This would require the time of the surgeon or his assistant, throughout each exercise, for revolving the cards. Depressing the handle would make the printed word incline toward the opposite side; and to keep the two words fused, the superior obliques would be called into action. Again, raising the handle, so that the pointer shall stand at zero, will bring the two words into a horizontal line, and thus cause the superior obliques to relax. Repeating these steps, alternate contraction and relaxation of the superior obliques can be

accomplished. This exercise stopped short of fatigue would tend to strengthen these muscles, and thus cure the plus cyclophoria.

In minus cyclophoria the discs would have to be so rotated as to make the words incline toward the corresponding side, in order to call into action the inferior obliques.

The Stevens clinoscope also can be used for exercising the obliques; but this, too, would require the time of the surgeon or his assistant. The discs used should be those marked with the diameter, and not with the radius, unless the two radii should be made both to point in the same direction. The former would be better. The discs could be placed with the diameters either vertical or horizontal. Revolving the two tubes, so that the indicators would point toward each other, would call into action the superior oblique muscles; but when made to diverge from each other, the inferior obliques would be called into action. Reversing the revolution, in either case, so that each indicator would stand at zero, would bring the obliques into the state of rest. In this way rhythmic exercise of the obliques may be accomplished, and a plus or minus cyclophoria cured.

The cyclo-phorometer likewise can be used for exercising the obliques; but this, too, would require the time of the surgeon or his assistant. It should be adjusted

for easy fusion of the two streaks of light, as if for the purpose of taking the cyclo-duction. Revolving the two rods, so that the indicators would move in the temporal arcs, would call into action the superior obliques; and revolving them so that the indicators would move in the nasal arcs would call into action the inferior obliques. In either case, reversing the motion, so that the indicators may be made to stand at zero, would cause relaxation of these muscles. The revolutions could be repeated so as to cause rhythmic exercise of the obliques, and thus cure cyclophoria. The displacement should not be more than half that for cyclo-duction in either of these methods.

Whether the one or the other of these means should be used, the exercise should not cause fatigue, and in no case should it be continued longer than ten minutes. It need not be repeated oftener than once a day.

The only means for exercising the oblique muscles, which a patient can use without assistance, consists of a pair of cylinders set in circular rims, so that they may be turned in the proper directions for displacing a horizontal line so as to call into action the proper muscles in the treatment of cyclophoria. The frames for this purpose are made of German silver, with circular rims. These rims are deeply grooved to allow a free rotation of the lenses. The rims are marked at points fifteen degrees apart, from 90° to 45°, in either the lower tem-

poral or lower nasal quadrant, depending on the pair of muscles affected. The cylinders used are usually plus 1.50 D., and the axis of each is plainly marked, as shown in the cuts. The frames are not marked, nor are the cylinders cut, except by the oculist's order.

Fig. 31 represents a pair of exercise cylinders ordered for a patient's own use, whose superior obliques are insufficient. The rims, as shown, are marked in the lower

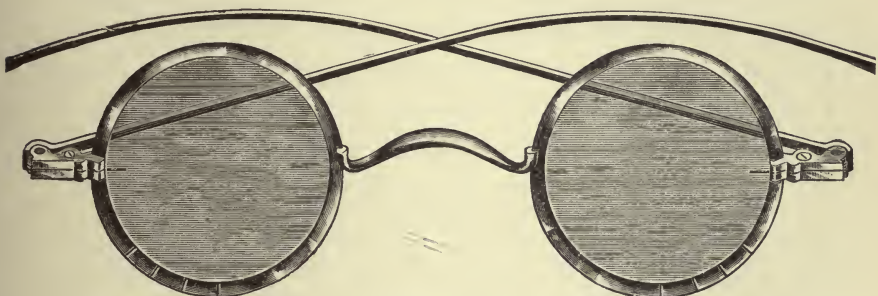

Fig. 31.

temporal quadrant, at four points fifteen degrees apart, three of which are numbered 1, 2, and 3. The cylinders, whose axes are distinctly marked, can be readily revolved. The patient is directed to place the mark on each lens at the notch marked No. 1. Placing them now before her eyes, she is instructed to look at a horizontal line eight or ten feet distant for five seconds, then without them for five seconds, then again with them for five seconds, and so on

for five minutes. Now the two lenses are to be revolved so that their marks point to the No. 2 notch on the rim. The line is now looked at, as above, for three minutes. Now the last change in position of the lenses is made by revolving their marks to notch No. 3, the point of maximum action. The patient again looks at the line, as above, for two minutes, which ends the exercise for that day—ten minutes in all.

The marking of the rims must be in the lower nasal quadrant when the patient has insufficiency of the inferior obliques, the exercise lenses to be plus cylinders. The revolution is made in the direction of the notching in both classes of cases. The points at which to stop and the time to look at the line are the same for both plus and minus cyclophoria. The exercise is accomplished by raising and lowering the frames at intervals of three seconds. This exercise should not be carried to the point of fatigue, nor should it be continued longer than ten minutes.

Once a day is sufficiently often to resort to the exercise. The lightest work is done when the axes of the cylinders stand at the first notch, and it is continued longest; while the heaviest work is demanded when the axes stand at the highest notch, and for this reason it is continued the shortest time.

It is clear that these cylinders are intended for the production of artificial oblique astigmatism, which must

effect the same changes in images as are found in natural oblique astigmatism. Plus cylinders revolved as shown in Fig. 31 make the meridians of greatest refraction diverge from each other above; for the axes of the cylinders, representing the meridians of least curvature, converge above. These cylinders make horizontal lines dip toward the opposite side. To keep the images fused, the superior obliques must tort the eyes in. Raising the frames, the images of the horizontal line are no longer oblique, hence the muscles that torted the eyes in must now relax.

If minus cylinders are used, their axes should be placed in the nasal arcs of the frames for exercising the superior obliques, and in the temporal arcs for exercising the inferior obliques. The axis of the minus cylinder represents the meridian of least refraction, hence the need for rotating it in a direction different from that for the plus cylinder.

The cylinders, whether plus or minus, may be of any strength from .50 D to 1.50 D. Rarely should the cylinder be stronger than 1.50 D.

These cylinders were first used for exercising the obliques on May 17, 1892. The first case was cured of a plus cyclophoria after a reasonably short time of faithful exercise, and remains cured to this day—September 26, 1901.

Operative Treatment.

A plus cyclophoria uncomplicated by any other form of imbalance, if high in degree and unrelievable by non-surgical means, should be treated by operating on both superior recti, dividing only their nasal fibers; or by operating on both inferior recti, shortening or advancing their nasal fibers. In either case, the cyclophoria would be cured and double cataphoria would be developed.

A plus cyclophoria complicated by a double hyperphoria should be relieved by cutting the nasal fibers of both superior recti, which should result in a cure of both conditions.

A plus cyclophoria complicated by double cataphoria should be treated by dividing the temporal fibers of both inferior recti.

A plus cyclophoria complicated by right hyperphoria and left cataphoria calls for a division of the nasal fibers of the right superior rectus and the temporal fibers of the left inferior rectus. These operations should cure both conditions.

A plus cyclophoria complicated by sthenic esophoria should be treated by dividing the lower fibers of both interni; but when the esophoria is asthenic, the operation should be a shortening or advancement of the lower fibers of both externi.

A plus cyclophoria complicated by sthenic exophoria

calls for a division of the upper fibers of both externi; but when the exophoria is asthenic, the upper fibers of both interni either should be shortened or advanced.

A plus cyclophoria complicated by sthenic esophoria, right hyperphoria, and left cataphoria, demands that the lower fiber, of the left internus should be divided, so as both to elevate the cataphoric eye and tort it in. If there remains some of both the plus cyclophoria and right hyperphoria, the nasal fibers of the right superior rectus should be cut.

A plus cyclophoria complicated by sthenic exophoria, right hyperphoria, and left cataphoria, calls for a division of the upper fibers of the right externus, so as both to depress the hyperphoric eye and tort it in. Should there remain some of the plus cyclophoria and left cataphoria, the temporal fibers of the left inferior rectus should be severed.

Very rarely there is minus cyclophoria, either complicated or uncomplicated, that calls for surgical treatment. It only must be remembered that the part of a muscle cut, shortened, or advanced for plus cyclophoria must remain intact when the condition is minus cyclophoria; and that the margins left intact in the treatment of plus cyclophoria must be either divided, shortened, or advanced for minus cyclophoria.

Plus cyclophoria of the right eye and minus cyclopho-

ria of the left eye (parallel cyclophoria), if uncomplicated, calls for a division of the nasal fibers of the right superior rectus and the temporal fibers of the left superior rectus. While these operations would parallel the vertical axes of the eyes with the median plane of the head, they would develop a double cataphoria. A case of this kind, complicated by right hyperphoria and left cataphoria, calls for a division of the nasal fibers of the right superior rectus and the nasal fibers of the left inferior rectus.

The obliques themselves should never be subjected to an operation for cyclophoria; but, as will be shown in the next chapter, the inferior oblique may be divided when there is plus cyclotropia.

CHAPTER VIII.

COMPENSATING CYCLOTROPIA.

THE law governing the oblique muscles is that they must keep the vertical axes of the two eyes parallel with the median plane of the head. They do this in obedience to the unalterable law of corresponding retinal points, and must do it in all states of refraction not causing a displacement, in opposite directions, of the two retinal images as related to the one object. They must also maintain this parallelism of the vertical axes in those eyes whose refractive condition displaces both images, but in the same direction and to the same extent. In emmetropia, hyperopia, and myopia there is no displacement of images; hence the law of corresponding retinal points is satisfied when the obliques obey the subordinate law governing them—that is, when they parallel the vertical axes with the median plane of the head. In vertical and horizontal astigmatism there is no displacement of images of vertical and horizontal lines—lines that are parallel with the two principal meridians—while images of oblique lines are displaced, but

in the same direction and to the same extent in the two eyes; hence the law of corresponding retinal points can be satisfied only when the subordinate law governing the obliques is obeyed.

In oblique astigmatism, with the meridians of greatest curvature either diverging or converging above, the images of vertical and horizontal lines are displaced so that they no longer bear a proper relationship to the lines themselves; hence the images must fall on non-corresponding retinal points—more properly, *lines*. In such eyes, no line in space can have both images properly related to it, for a line that would be parallel with the meridian of greatest curvature of one eye would not be parallel with the meridian of greatest curvature of the other; therefore, while in the former the line and its image would be properly related, in the latter this could not be, for the image would be displaced. The two images of no line can fall on corresponding retinal parts when, in oblique astigmatism, the meridians of greatest curvature are not parallel. To harmonize these images, and satisfy as best possible, but never perfectly, the law of corresponding retinal points, the individual law governing the obliques must be suspended, and the vertical axes of the eyes must be made to either converge or diverge above—the former if the meridians of greatest curvature diverge above, the latter if these meridians

converge above. The same is true when the principal meridians of one eye are vertical and horizontal, while those of the other are oblique.

While there seems to be no one who now doubts that, in astigmatism, there is displacement of the images of all lines not parallel with the one or the other of the two principal meridians, it will not be out of place here to present some incontrovertible demonstrations, showing that these displacements are always toward the meridian of greatest curvature.

The accompanying illustrations are simple, are easily understood, and are at the same time correct. These, at a glance, make clear what has been taught since 1891 concerning the obliquity of retinal images in oblique astigmatism. Criticism of this teaching would not have been made if the author had thought to use these illustrations in his first publication.*

In justice to Dr. F. C. Hotz, of Chicago, it must be stated here that he gracefully retracted his criticism, which was most severe, and showed before the Chicago Ophthalmological Society how it was that he was led into the error that formed the basis of his criticism. It was before this society that he thought he had demonstrated that oblique astigmatism did not cause any displacement of the retinal image of a vertical or horizontal

*See Ophthalmic Record, Vol. I., No. 1, 1891.

line. He used for this purpose a camera, the lens of which he had rendered astigmatic by adding a cylinder with its axis at 45°. On the ground glass of his camera he focused the image of a horizontal line. This image he believed to be horizontal, as did all who saw his demonstration, but it was not. With the same camera, he later focused the images of two lines crossing each other at right angles—the one line, vertical; the other, horizontal. These images were readily seen displaced, in opposite directions, so that the angles formed at their point of crossing were not right angles. These two lines enabled the camera to magnify the truth so as to enable Hotz and his fellow-members of the Ophthalmological Society to see the error into which he had led them at a previous meeting. Hotz was kind enough to invite the author, whom he had formerly criticised, to be present at his last demonstration and speak on oblique astigmatism.

Dr. Harold Wilson (of Detroit), another critic, was later forced to yield to the argument of his camera rendered astigmatic, which he had focused on a church spire. He thought that the spire in the photograph was vertical, and so published. Later he studied both the axis of the spire and the base-line, and found that the photograph did not show them to be at right angles; that these were both inclined in opposite directions. His error in

observing only one line was very similar to the one into which Hotz had fallen.

But to a study of the illustrations:

Fig. 32 is complex, showing a square as seen by a non-astigmatic eye, as seen by an eye astigmatic according

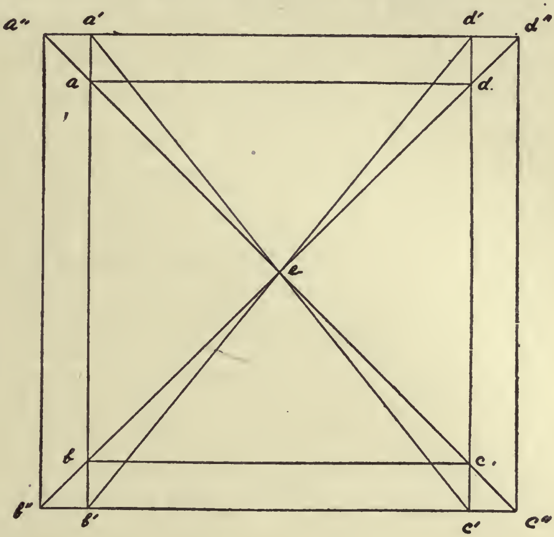

Fig. 32.

to the rule, and as seen by the latter after the astigmatism has been corrected by a plus cylinder. The rectangle *a-b-c-d* is the square seen by the non-astigmatic eye, and *a-c* and *d-b* show the diagonals of this square. The rectangle *a'-b'-c'-d'* is the figure seen by the astigmatic eye with the meridian of greatest curvature verti-

cal. The axial rays from the ends of the lines *a-b* and *d-c* enter the eye through parts of the cornea parallel with the meridian of greatest curvature and so near to it that their refractive power is practically the same. The refraction of these axial rays from *a* and *b*, by the cornea, is such as to make them cross each other, on their way back to the retina, sooner than they would have done if there had been no astigmatism; hence their points of impingement on the retina are more widely separated, and the line itself must be proportionately increased. The same is true of the axial rays from the ends of the line *d-c*. Hence it is clear that the line *a-b* must become the line *a′-b′* and the line *d-c* must become the line *d′-c′*. Because of the increase of the length of the line *a-b* and *d-c* the lines *a-d* and *b-c* are more widely separated, becoming lines *a′-d′* and *b′-c′*, and we have—not a square, but—the rectangular parallelogram *a′-b′-c′-d′*. The diagonal *a-c* has been rotated toward the vertical and becomes *a′-c′;* and the diagonal *d-b* has been rotated in the opposite direction, but also toward the vertical, and becomes *d′-b′*. They have both been rotated, by the refraction of the astigmatic cornea, toward the meridian of greatest curvature. The image changes effected by the astigmatic cornea are, as shown in the figure: an increase in the length of the lines parallel with the meridian of greatest curvature, an increase in the distance

between the lines parallel with the meridian of least curvature, and a corresponding rotation of the diagonals toward the meridian of greatest curvature. The proper plus cylinder placed before this eye gives such aid to the least curved meridian of the cornea as to make its refractive power exactly equal to the unaided refractive power of the meridian of greatest curvature. The result will be a lengthening of the horizontal lines a'-d' and d'-c' into the lines a''-d'' and b''-c'' and a displacement of the lines a'-b' and d'-c' until they become a''-b'' and d''-c''. Since two of the sides (a-b and d-c) of the square have been lengthened by the astigmatism and the remaining two sides (a-d and b-c) have been lengthened to exactly the same extent by the correct plus cylinder, the figure a''-b''-c''-d'', seen by the corrected astigmatic eye, is a square. The cylinder, in changing the rectangular parallelogram a'-b'-c'-d' to the square a''-b''-c''-d'', has also rotated the diagonals a'-c' and d'-b' back to their original positions; for the diagonal a''-c'' coincides with the diagonal a-c, and the diagonal d''-b'' coincides with d-b.

If the astigmatism had been corrected by a minus cylinder, the lines a'-b' and d'-c' would have been shortened into the lines a-b and d-c; the lines a'-d' and b'-c' would have been brought close together, a'-d' becoming a-d and b'-c' becoming b-c; and the diagonals a'-c' and

d'-b' would have been rotated back into the diagonals *a-c* and *d-b*, respectively, so that the figure thus seen would be the square *a-b-c-d*. Thus it is shown that an astigmatic eye, corrected with a minus cylinder, sees the square with the same measurements as that seen by the non-astigmatic eye; while the square seen by the astigmatic eye, corrected with a plus cylinder, is magnified.

Turning the right side of Fig. 32 up, it shows the image changes when the meridian of greatest curvature is horizontal. In either case the lines parallel with the meridian of greatest curvature are made longer by the astigmatism, with a corresponding increase of distance between the lines parallel with the meridian of least curvature, and the diagonals are rotated toward the meridian of greatest curvature.

If there is astigmatism of one eye with the meridian of greatest curvature vertical and astigmatism of the same kind in the other with the meridian of greatest curvature horizontal, the former would see a square changed into a rectangular parallelogram, with the longer sides vertical; while the latter would see the square similarly changed, but with the longer sides horizontal. The images in such eyes would be dissimilar and could not be perfectly fused; correcting cylinders would make the images alike and thus make complete fusion possible.

What is true of squares is true of rectangular paral-

lelograms, as shown by Fig. 33, in which there is the same proportionate lengthening of two of the sides by the astigmatism, and of the other two sides by the astigmatic correction with plus cylinders, also the same char-

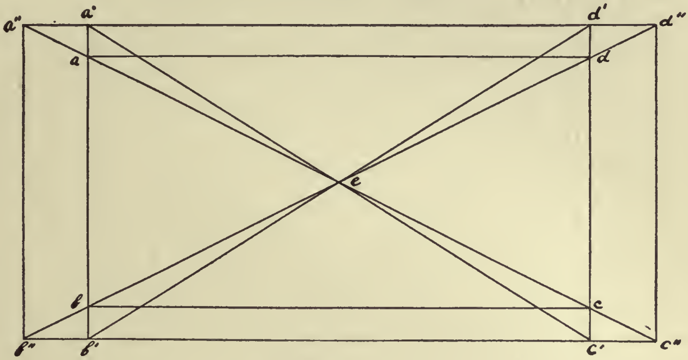

Fig. 33.

acter of rotations of the diagonals, the principal meridians being vertical and horizontal.

Fig. 34 shows the image changes when the astigmatism is oblique, the meridian of greatest curvature being at 135°. That part of the complex figure shown by *a-b-c-d* is a square as seen by a non-astigmatic eye. Looked at by the oblique astigmatic eye already mentioned, the diagonal *a-c*, being at an angle of 135°, is in a plane with the meridian of greatest curvature, while the diagonal *d-b* is in a plane with the meridian of least curvature. For reasons already given in discussing

Fig. 32, the diagonal *a-c* is increased in length by the astigmatism into *a′-c′*, while the diagonal *d-b* is neither altered in length nor in direction. The sides of the square, not being parallel with the principal meridians, must be rotated toward the meridian of greatest curvature, *a-b*

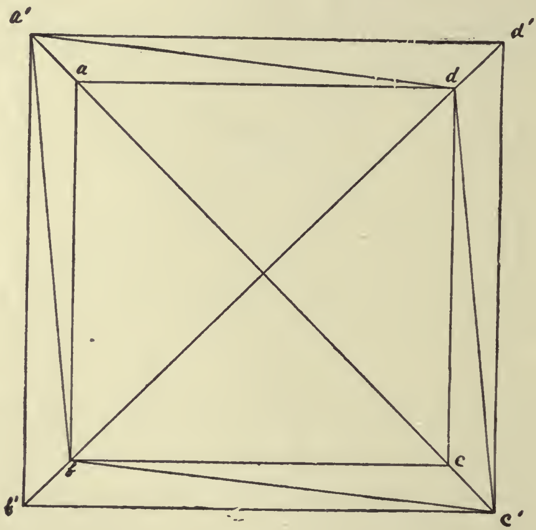

Fig. 34.

becoming *a′-b*, *a-d* becoming *a′-d*, *b-c* becoming *b-c′*, and *d-c* becoming *d-c′*. The figure *a′-b-c′-d* is a non-rectangular parallelogram leaning down and to the right. A plus cylinder correcting the astigmatism will increase the length of diagonal *d-b* into *d′-b′* to exactly the length of the diagonal *a′-c′* and at the same time will rotate the

lines a'-b to a'-b', a'-d to a'-d', c'-b to c'-b', and c'-d to c'-d', thus converting the non-rectangular parallelogram a'-b-c'-d into the magnified square a'-b'-c'-d'.

Turning the right side of Fig. 34 up, the image changes are shown when the meridian of greatest curvature is at 45°. It is clear that, if the astigmatism is equal and of

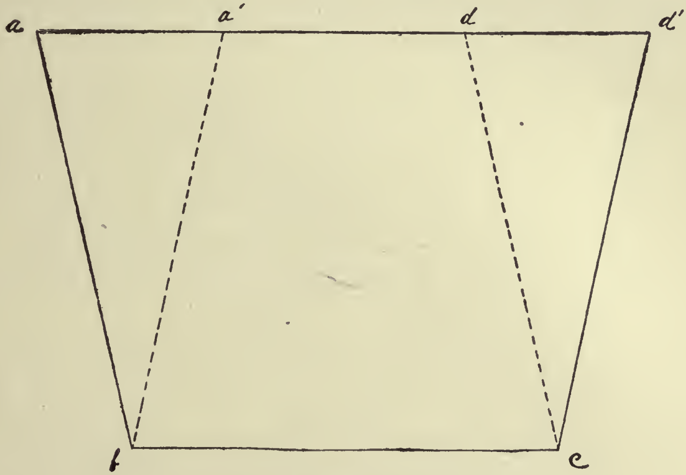

Fig. 35.

the same kind in the two eyes, the meridians of greatest curvature being parallel, though oblique, the two images of a square held vertically will be distorted alike, and hence will fuse readily and completely. If the meridian of greatest curvature in the right eye is at 135°, and in the left eye at 45°, the image in each eye will be a non-

rectangular parallelogram leaning in the opposite direction from the image in the other eye; and the two cannot be perfectly fused, though an attempt at fusion will be made, in an effort on the part of the eyes to obey the supreme law of binocular single vision, the law of corresponding retinal points.

Fig. 35 shows how the fusion of the images would make the square appear. This fusion is effected by the superior obliques converging the vertical axes of the eyes.

Soon after Hotz and Wilson had tried the camera and had published their conclusions unfavorable to the distortion of retinal images by oblique astigmatism, Dr. Perry, of Oneida, N. Y., betook himself to the camera, with the result shown in the accompanying half-tone cut, Fig. 36:

Dr. Perry's own words, descriptive of this cut, are as follows:

"Fig. 36 was produced by taking a photograph of the graduated circle with printed words as shown; and then, without moving camera or object, placing a .50 D cylindrical lens in front of the objective and exposing a second negative, and, when the photographs were finished, cutting away the outer circle from the astigmatic print and pasting it over the other in such a way as to make the horizontal and vertical lines, respectively, coincide on the two prints. If the cut is held so that the line of the

Fig. 36. (335)

print reading 'Astigmatism Oblique, 135°,' is horizontal, it will be observed that the distortion of the field is such that this particular line is moved along the scale nearly two degrees, while the line which is perpendicular to it is moved an equal distance, but in a contrary direction. This shows what must happen to a retinal image in oblique astigmatism."

Dr. Lowry, at the time a private student of the author, was incited by the published criticisms of Hotz and Wilson to use his camera. Half-tone cuts were made from his photographs, and, notwithstanding these speak for themselves, his descriptive text is here reproduced:

"It has often been noted that the camera obscura is very strikingly similar, in its mechanism, to the human eye. In this simple optical instrument we have a mechanical eye, so far as refraction is concerned. If we compare to the eye the component parts of the photographic camera, which is merely a camera obscura with a device for receiving the image on a sensitized plate, we find the refractive media of the former correspond to the photographic lens; the iris, to the stop; the accommodation, to the focusing apparatus; and the retina, to the ground glass. Focus the camera properly, and we have the emmetropic eye. By placing a concave cylindrical lens, axis at 90°, in apposition to the photographic lens, we have simple hypermetropic astigmatism according to

the rule; if we place the axis at 180°, we have simple hypermetropic astigmatism against the rule; if we place the axis anywhere between the vertical and horizontal,

Fig. 37.

we get oblique astigmatism. Whether or not the image will be oblique on the ground glass will be seen later.

"To illustrate these points, I have made the accompanying photographs with a rapid rectilinear lens, used in the Rochester Optical Company's 5 x 7 midget camera. The camera was not moved or changed in any way for

the first five photographs. Fig. 42 was made at another time. The rectangle was made mathematically accurate on a piece of cardboard 24 x 30. The lines, one inch wide,

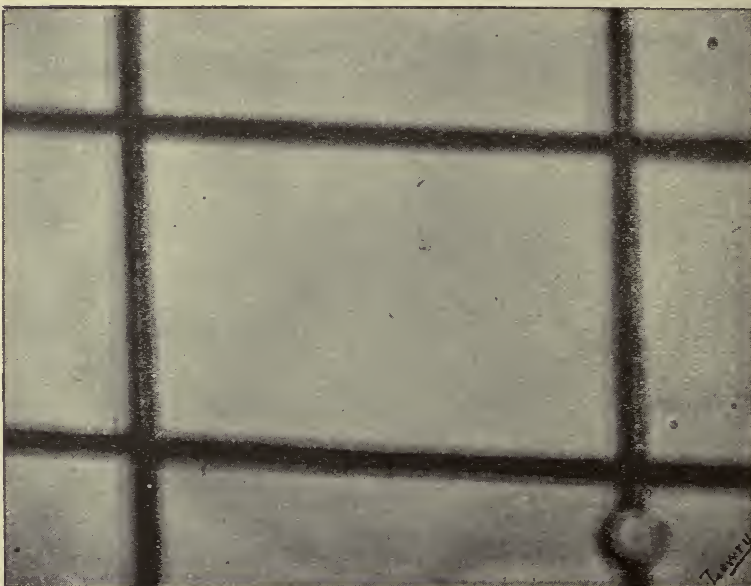

Fig. 38.

are prolonged beyond the rectangle to show more clearly the obliquity of images that may be produced by the cylinders obliquely placed. The watch is used as a plumb, and is seen in the same position in all. The photographs are not inverted as the images would be on the ground glass or the retina.

"In Fig. 37, no cylindrical lens is used, and we get a perfect rectangle, sharp and distinct in its outline, as would be seen by an emmetropic eye.

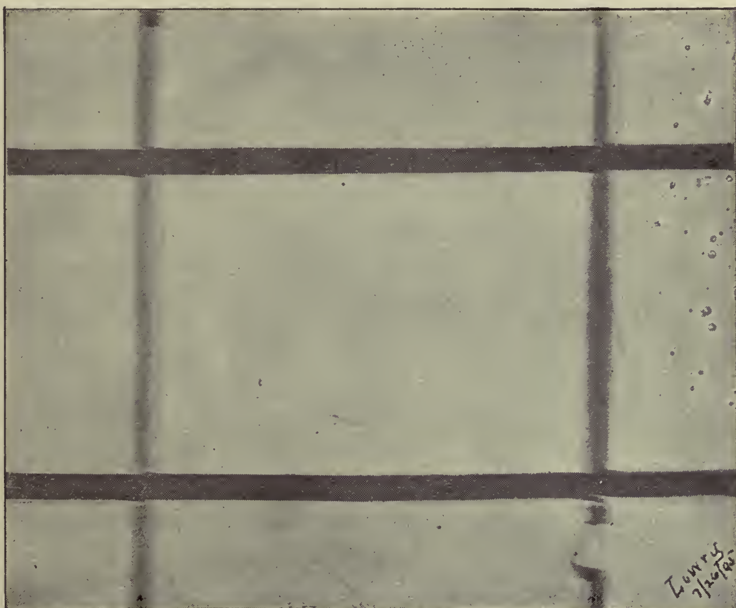

Fig. 39.

"In making Fig. 38 a minus 3 D. cylindrical lens is placed just in front of, and in apposition to, the photographic lens, with its axis at 45°. * A plus 1.50 D spherical lens is used with the cylinder in order to give the

* These prints are all the reverse of the images, therefore the reverse of the object as it would be seen.—AUTHOR.

middle of the focal interval without changing the camera. In this the vertical and horizontal lines are equally indistinct. The vertical lines deviate to the left at the top,

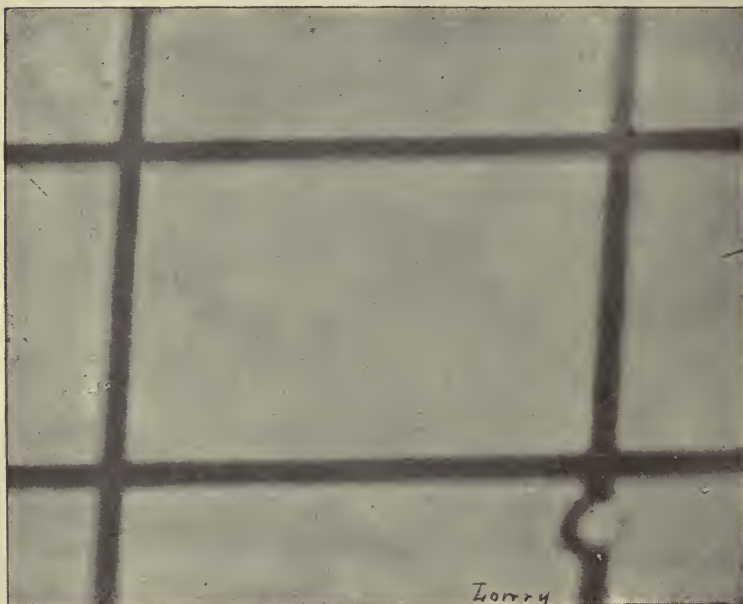

Fig. 40.

and to the right at the bottom, while the horizontal lines are depressed at the right and elevated at the left. The plumb shows that the card is in just the same position as in Fig. 37, and the camera has not been moved from its original position. This picture is clearly a non-rectangular parallelogram.

"If the axis of the cylinder be changed to 90°, we get Fig. 39, which represents simple vertical hypermetropic astigmatism. This is made without the plus 1.50 D sphere and without the camera's being changed in the least from

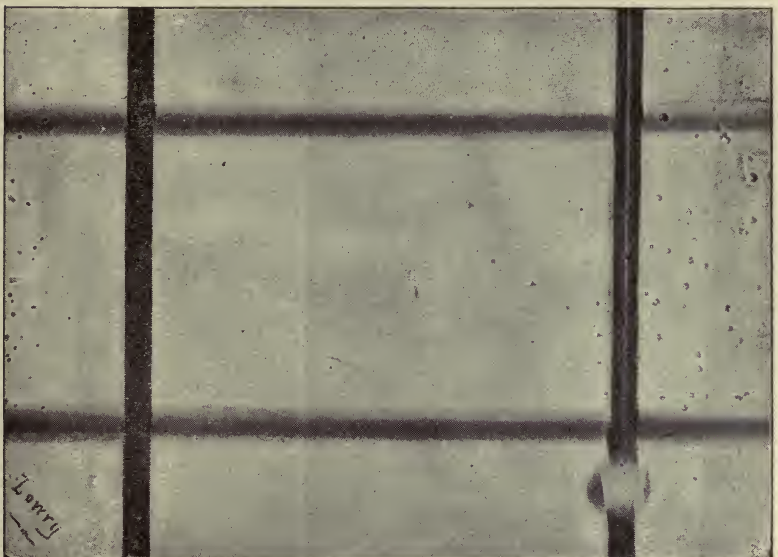

Fig. 41.

its position in Fig. 37 and Fig. 38. The meridian of greatest curvature here is at 90°, with the least at 180°. It is a perfect rectangle, with its horizontal lines sharply cut and the vertical very indistinct.

"Now if we place the axis of the cylinder at 135°, again adding the plus 1.50 D sphere, a non-rectangular

parallelogram is formed with its sides deviating in the opposite direction to those in Fig. 38. This is shown in Fig. 40. Every part is equally indistinct, and nowhere are the lines at right angles as in the original.

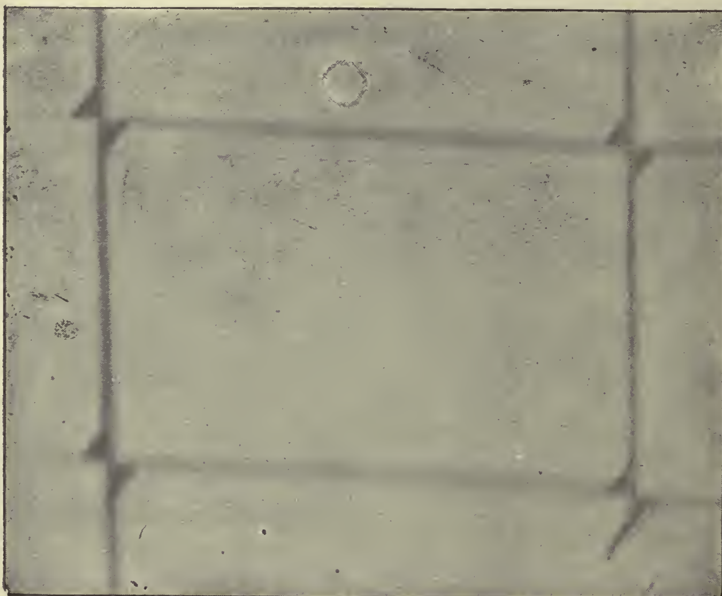

Fig. 42.

"By placing the axis of the cylinder at 180°, without the plus 1.50 D sphere, we produce simple hypermetropic horizontal astigmatism, the effect of which is illustrated in Fig. 41. Here we have the meridian of greatest curvature at 180°, and the least at 90°. We obtain a perfect

rectangle, with its vertical lines clear and its horizontal very indistinct, in contradistinction to Fig. 39.

"Fig. 42 is the same as Fig. 38 without the plus 1.50 D sphere to give the focal interval, nor is the camera refocused to give it. This photograph was made at a different time, and the camera was not in exactly the same position as for the other five. An eye with the meridian of greatest curvature at 45° and 3 D of simple hypermetropic astigmatism would see the object as shown in this figure, if, under the influence of a mydriatic or in old age, it were relieved of all ciliary action. The rhomboidal figures are seen very clearly here at the angles and on the watch.

"Suppose one of the meridians of greatest curvature to be at 45°, and the other at 135°, one image would be seen as in Fig. 38, and the other as in Fig. 40; in obedience to the law of corresponding retinal points, we would have these two figures superimposed, forming a trapezoid. If the meridians diverged above, we would have the long side above, and the short side below. In this form of astigmatism we would not only have a ciliary strain, but the superior obliques would make an attempt to bring the harmonizing parts of the two retinas under the dissimilar images in order to have a single object. If the meridians converged above, the short side of the trapezoid would be above, and the long side below. This fu-

sion of dissimilar parallelograms into a trapezoid, long side below, would be effected by the inferior obliques.

"But the bone of contention has been principally the question of the deviation or the non-deviation of the image on the retina in oblique astigmatism. Others have proved it by the laws of optics, by clinical experience, and by logical reasoning; and it seems to me that my photographic demonstrations have added very conclusive evidence to the theory that, in oblique astigmatism, the retinal images of vertical and horizontal objects deviate from their normal direction."

Since 1887, it has been taught that, in oblique astigmatism, abnormal work is required of the obliques. However, it was not until 1891 that the cause of this abnormal action on the part of the obliques was discovered to be a want of parallelism of the meridians of greatest curvature of the corneas and a consequent dissimilar distortion of retinal images. It was then announced that, in oblique astigmatism, be the obliquity much or little, it is a physical impossibility for a horizontal line and its retinal image to lie in the same plane.* The same is true of all lines not parallel with one or the other of the two principal meridians.

The obliquity of retinal images was first demonstrated, in the latter part of 1890, by the production of artificial

*See Ophthalmic Record, Vol. I., No. 1.

oblique astigmatism, at which time the following law was formulated: "*The retinal image is displaced toward the meridian of greatest curvature.*" This being true—and there is no exception to this rule—the image of a vertical or horizontal line is displaced toward the meridian of best curvature in oblique hyperopic astigmatism, from the best meridian in oblique myopic astigmatism, and toward the myopic meridian in oblique mixed astigmatism.

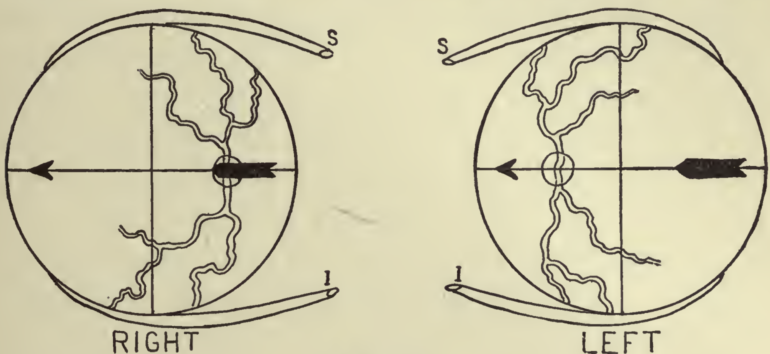

Fig. 43.

As a result of the experiments with artificially produced astigmatism, the next eight figures were constructed, some of them showing the character of the images of a horizontal arrow, formed on the two retinas; while other of these figures show clearly the compensating cyclotropia made necessary that the images might be fused. This cyclotropia corresponds with the compensating esotropia which occurs when both images are dis-

placed by prisms with their bases out; with the compensating exotropia, when images are displaced by prisms with their bases in; with the compensating hypertropia of one eye and catatropia of the other, when a prism is base down before one eye and base up before the other. In either case, the turning must occur in obedience to the supreme law of binocular single vision, the law of corresponding retinal points.

Fig. 43 represents a pair of eyes in which the two principal meridians are vertical and horizontal (they can also represent eyes that are non-astigmatic). If an arrow, or the picture of an arrow, be held horizontally before these eyes, the arrow-head toward the patient's left eye, it will throw a reversed image on each retina, and the two images will be in the same plane with the object. These two images fall on parts of the two retinas that act together; hence, but one object is seen.

Fig. 44 represents a pair of eyes in which there is hyperopic astigmatism, either simple or compound. The left eye has its best meridian vertical. In this eye the arrow, held as before, throws its image on the horizontal meridian of the retina, hence in the same plane with it. In the right eye the best meridian is at 135°, as shown by the dotted line. In obedience to the well-known law of refraction by curved surfaces, the image of the same arrow must be oblique in this eye, and, hence, not in the

same plane with the object. The obliquity of the image will be greater or less, depending on the quantity of the astigmatism. It is represented as falling on meridian 170° of the retina. The horizontal image in the left eye

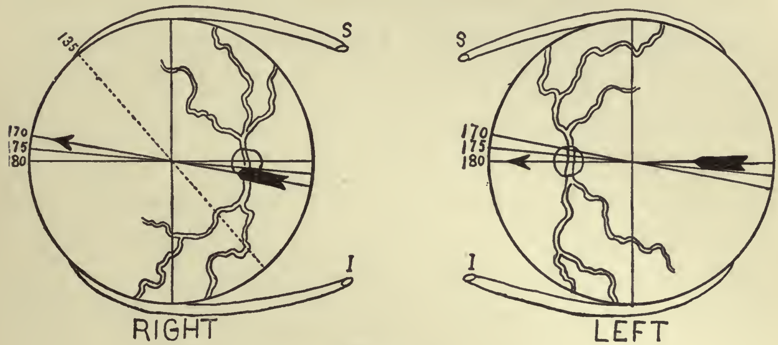

Fig. 44.

and the oblique image in the right eye do not fall on parts of the two retinas that harmonize. The direction of either image in relation to the other cannot be changed except by artificial means—a proper cylindrical lens.

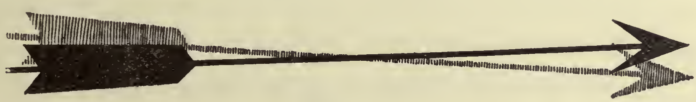

Fig. 45.

This being true, the pair of unaided astigmatic eyes, represented by Fig. 44, must see the arrow double, as shown in Fig. 45, unless something is done by the eyes themselves for the purpose of harmonizing the images.

In all cases of oblique astigmatism, unless the obliquity is in the same direction in the two eyes, and the astigmatism the same in kind and quantity, something must be done in order to prevent double vision, as represented in Fig. 45. There are but two ways of accounting for the absence of this peculiar kind of double vision in such forms of astigmatism as that represented in Fig. 44. Sectional ciliary contraction would account for it. If it were possible for the ciliary muscle thus to act, one can readily understand how the curvature of the lens could be so changed as to result in lenticular astigmatism equal, but at right angles, to the corneal astigmatism. If such ciliary action were to take place in the right eye of Fig. 44, the retinal image would not only be made as sharp as if in an emmetropic eye, but it would also be made to lose its obliquity, and thus double vision would be prevented. As beautifully as this sectional ciliary action would account for the absence of double vision in cases of oblique astigmatism, it is certainly a false theory, since, when all ciliary power has been suspended by atropine or age, the eyes are still able to do something by means of which the double vision represented by Fig. 45 is prevented.

There must be double vision, unless the oblique image in the right eye and the horizontal image in the left eye can be made to occupy corresponding parts of the two

retinas. This can be effected alone by the *harmonious symmetrical action of the superior oblique muscles.*

Fig. 46 shows how the eyes represented by Fig. 44 act in order to have the images fall on corresponding parts of the retinas. The superior oblique muscle of the right eye has so revolved it as to bring meridian 175° of the retina in position to receive the impress of the oblique image; while, at the same moment, the superior oblique

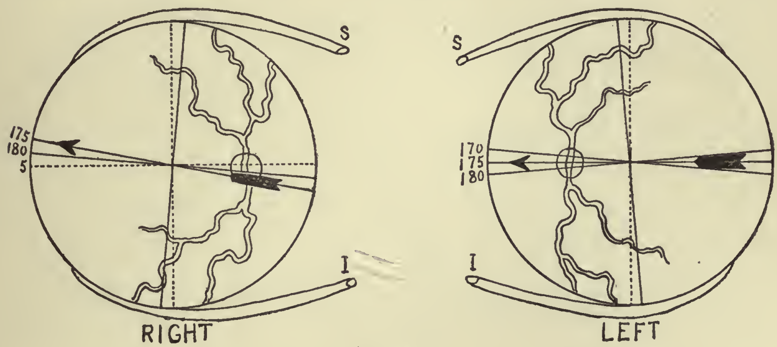

Fig. 46.

muscle of the left eye has so revolved it as to bring meridian 175° to the horizontal, hence in position to receive the horizontal image. The oblique and horizontal images being now on harmonizing portions of the retinas, there is no double vision.

Fig. 47 represents a pair of hyperopic astigmatic eyes, the left one having its best meridian vertical and the right one having its best meridian at 45°. In these eyes

there are a left horizontal image (image and arrow in same plane) and a right oblique image, this time on retinal meridian 10°. Nothing but artificial means will change the relative direction of these images; and there must be double vision, unless the oblique image can be made to fall on a portion of the retina that will harmonize with that portion of the other retina on which the horizontal image may fall.

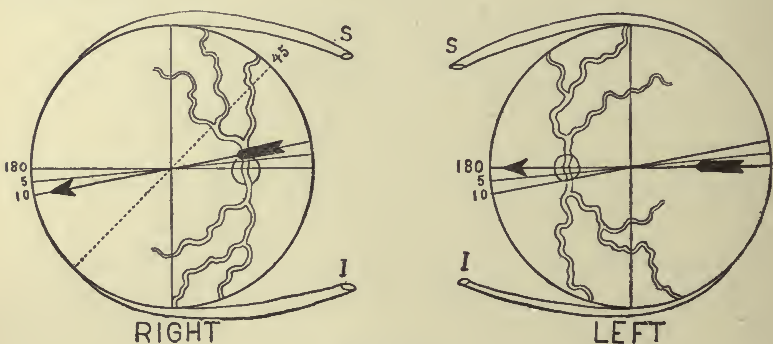

Fig. 47.

The double vision that would exist in astigmatic eyes represented in Fig. 47 is prevented by the harmonious action of the inferior oblique muscles, as shown by Fig. 48, the inferior oblique of the right eye bringing meridian 5° under the oblique image, while the inferior oblique of the left eye causes meridian 5° to come under the horizontal image. Thus the two images are made to fall on corresponding parts of the two retinas.

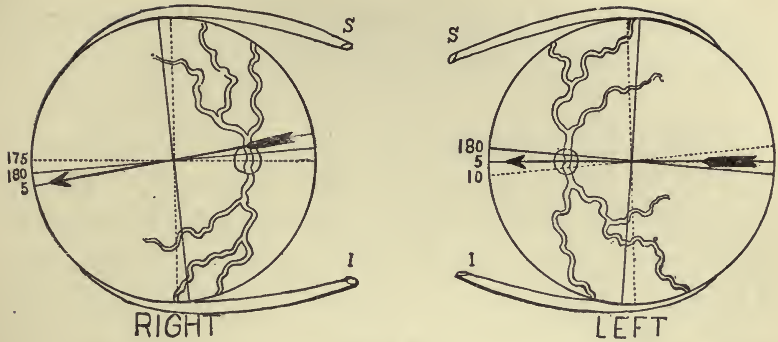

Fig. 48.

Fig. 49 represents a pair of hypermetropic astigmatic eyes, with half the quantity of astigmatism found in the eyes represented by Fig. 44 and Fig. 47; but in both eyes the best meridian is oblique—in the left eye at 45°, and in the right eye at 135°. An arrow held in the horizontal position before these eyes will throw an oblique image on each retina, the one in the left eye on meridian 5°, and the

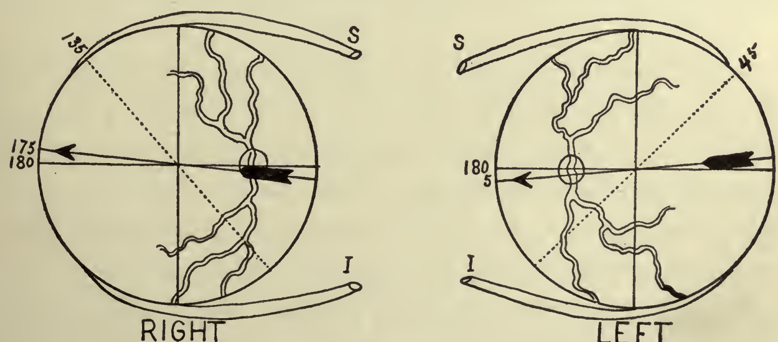

Fig. 49.

one in the right eye on meridian 175°. Without some change double vision, as shown in Fig. 45, will be inevitable.

In the oblique astigmatism of the two eyes represented by Fig. 49, the two oblique images are made to fall on corresponding parts of the two retinas by the harmonious action of the two superior oblique muscles, as shown in Fig. 50.

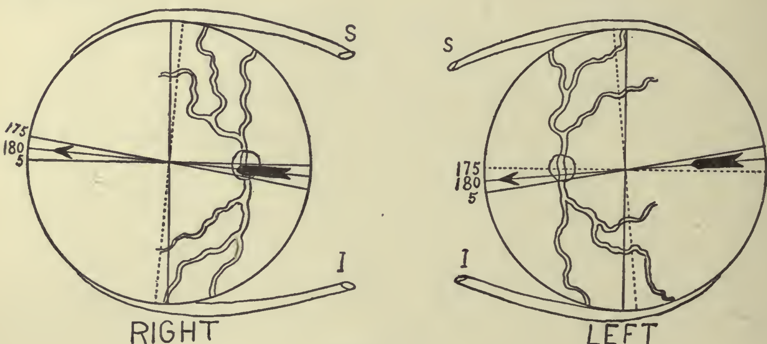

Fig. 50.

The obliquity of the image and the consequent strain on the oblique muscles fully account for the greater trouble attending oblique astigmatism than is found connected with astigmatism in the vertical or horizontal. As is well known, non-oblique myopic astigmatism is unattended by any sort of ciliary strain in distant vision.

In oblique myopic astigmatism, there is strain on either the two superior or the two inferior oblique muscles in

both distant and near seeing. In all other forms of non-parallel oblique astigmatism, there is likewise strain on the oblique muscles.

In all kinds of non-oblique astigmatism, also in simple hyperopia, the time comes when all nervous phenomena caused by their existence pass away. Their disappearance, being gradual, but finally complete, coincides with the failure and final loss of ciliary power brought about by advancing age. The symptoms caused by oblique astigmatism may be modified by old age putting at rest the ciliary muscles; but they cannot be made to vanish, for the oblique muscles are forced to continue to act in age as in youth, so as to harmonize the images on the two retinas.

The plates made to illustrate the paper read by the author at the meeting of the Eighth International Congress of Ophthalmology (Edinburgh, 1894), are both interesting and instructive. They are reproduced here, together with the descriptive text.

Plate I. represents a pair of eyes that are non-astigmatic; or, if astigmatism exists, the principal meridians are vertical and horizontal. These eyes are represented as looking at a rectangle. The line *ep* across the right eye is the horizontal meridian, and the line *gh* is the vertical meridian, while their point of intersection (5) is the macula. Similarly the line *ep* in the left eye rep-

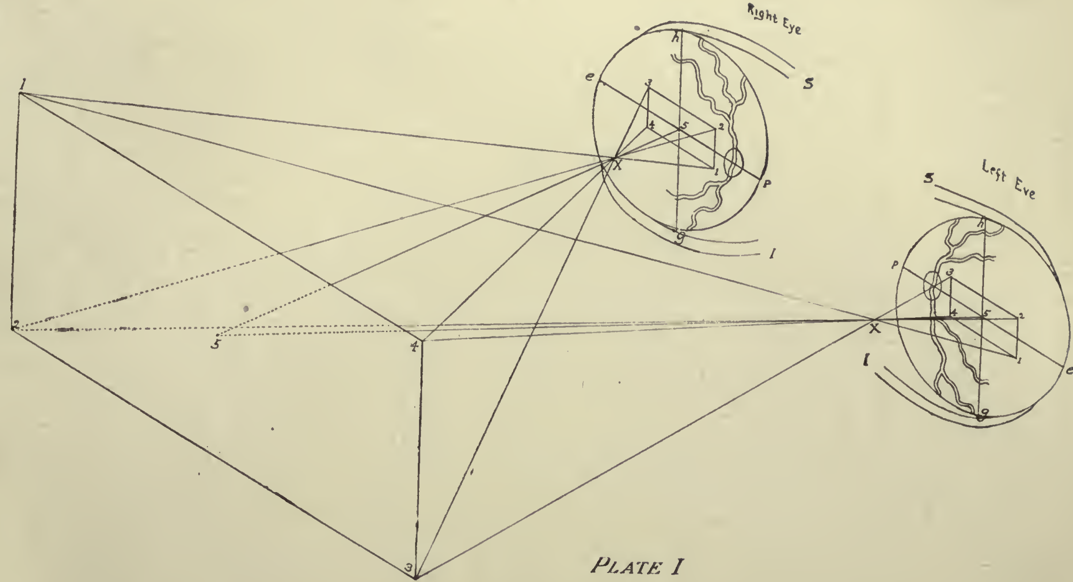

PLATE I

resents the horizontal meridian, and *gh* represents the vertical meridian, their point of intersection (5) being the macula. The vertical meridian of the right eye and that of the left eye are parallel. Point 5 in the rectangle is the point of fixation. The line 5-5 from the macula of the right eye is the visual axis of that eye, and likewise the line 5-5 is the visual axis of the left eye. These intersect at point 5 of the rectangle.

According to the well-known law of refraction by curved surfaces, such as are now under consideration, the rectangular object will throw a rectangular image on each retina, the size of which will bear a definite proportion to the size of the object. The center of retinal curvature of the right eye is *x*, through which all lines of direction from this eye must pass. The lower inner corner of this image is thus connected with the upper right-hand corner of the object by the line 1-1; in the same way the upper inner corner of the image is connected with the lower right-hand corner of the object by the visual line 2-2; and so on for the other corners of image and object. In like manner the corners of the rectangular image in the left eye may be connected with corresponding corners of the object by lines passing through the center of retinal curvature (*x*) of that eye. If the left eye should be excluded, the right eye would see the rectangle 1-2-3-4; if the right eye should be

screened, the left eye would see the same rectangular figure. Both eyes together, in obedience to both the law of corresponding retinal points and the law of projection, would see the one common rectangle 1-2-3-4. The superior and inferior recti in these eyes have kept the visual axes in the same plane, the external and internal recti have regulated their tension so that they have converged these axes to the point 5, and the superior and inferior obliques have kept the naturally vertical axes parallel with the median plane of the head.

The obliques have to perform only the simple function in oblique astigmatism, the meridians of greatest curvature being parallel, and the degree of astigmatism the same in the two eyes; but it would not be possible for such eyes to see the rectangle held in the position shown in Plate I. as a rectangle. Let the meridians of greatest curvature be at 45° in the right eye and also at 45° in the left eye. As a result of the refraction of the astigmatic cornea of the right eye, the rectangular figure would throw a parallelogram image on the retina, the image inclining down and out. A parallelogram image would be thrown on the left retina also, and it would incline down and in. Looked at with either eye alone, the rectangle would be seen as a parallelogram inclined down and to the right; looked at with both eyes, it would be a parallelogram of the same shape and inclination as

seen by each eye separately. The extrinsic muscles of these eyes have performed the same function as the muscles of the eyes shown in Plate I. and with the same result—viz., binocular single vision. The law of corresponding retinal points and the law of projection having full sway in both pairs of eyes, the one pair sees the figure as it is—a rectangle—while the other pair sees the same figure, when held in the same position, as a parallelogram leaning down and to the right. With the visual axes properly directed by the recti and the vertical meridians kept parallel by the obliques, the two eyes are kept so related that the two images of the object looked at fall on harmonizing parts of the two retinas, and the object is necessarily seen as one, and of the same shape as when seen with each eye separately.

In any state of refraction the relationship between corresponding points of the two retinas is unalterable. It is well known that, taken as a whole, the nasal half of one retina harmonizes with the temporal half of the other, and that all points of either retina bear a fixed and unalterable relationship to the macula and to the vertical and horizontal meridians. A retinal point in the nasal half of the right retina, bearing a definite relationship to the macula and the vertical and horizontal meridians, must harmonize with a point in the temporal

half of the left retina similarly located; and it can harmonize with no other retinal point under any conditions.

The complicated function of the obliques is necessary in oblique astigmatism when the meridians of greatest curvature diverge or converge above. This is necessary that they may bring harmonizing parts of the two retinas under dissimilar images, and thus insure binocular single vision; but, as will be shown, the object, though seen as one, will be distorted.

Plate II. may be taken for study. Both eyes have oblique astigmatism of the same kind and quantity. In the right eye the meridian of greatest curvature is at 135° and in the left eye at 45°. If the rectangular figure represented in Plate I. be held in the same position before the eyes represented in Plate II., it would not be seen with one eye alone or with both together as a rectangle. The rectangle shown in Plate I., when held before the right eye in Plate II., instead of throwing a rectangular, would throw a non-rectangular, parallelogram image on the right retina; the same rectangle would also throw a non-rectangular parallelogram image on the left retina. The state of refraction of the right eye would make the distorted image lean down and toward the left side, while the distorted image in the left eye would lean down and toward the right side. Cutting off the view of the left eye, the law of direction would

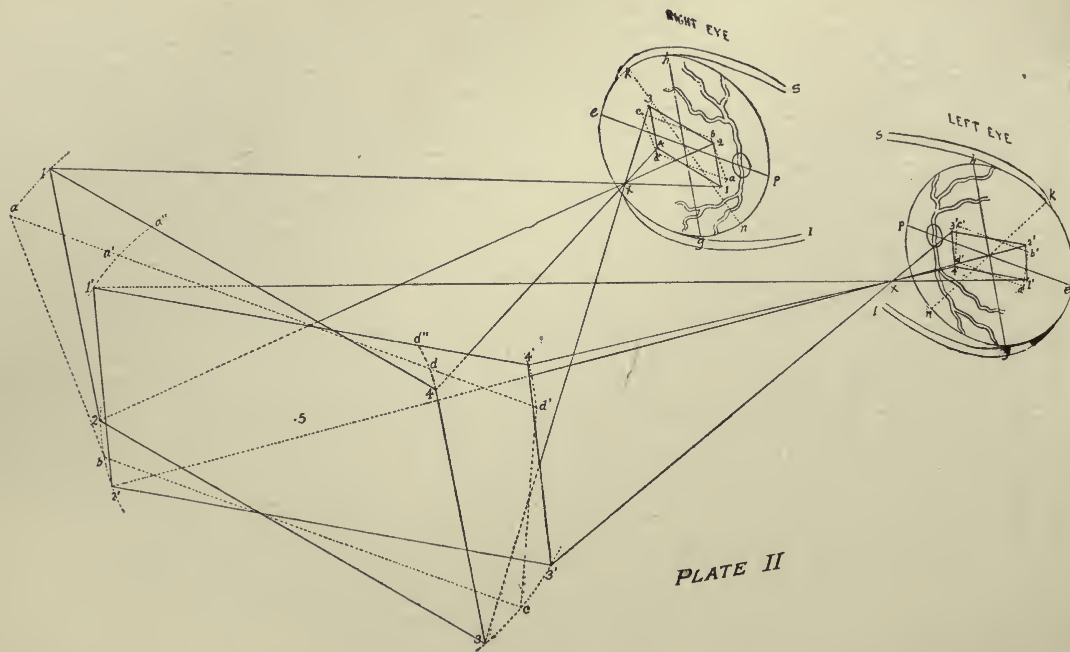

PLATE II

have full sway, while the law of corresponding points would be suspended. Since in one eye alone the law of direction is unalterable, all lines of direction must cross in the center of retinal curvature; and the right eye, with the parallelogram image leaning down and to the left, must see the figure casting the image, not as a rectangle, but as a parallelogram leaning down and to the left. Screening the right eye while the left eye looks on the rectangle, it is seen, not as a rectangle, but as a parallelogram leaning down and to the right, the law of direction determining the shape of the figure seen by the left eye, just as it fixed the shape of the figure seen by the right eye. Fig. 1-2-3-4 is what is seen with the right eye alone; Fig. 1′-2′-3′-4′ is what is seen by the left eye alone. The moment these two eyes are allowed to look at the rectangular figure, the law of corresponding retinal points is brought into conflict with the law of direction, and the latter is modified by the former. There is no necessity for changing the visual axes when looking at the rectangle with these two eyes; but, unless some change is effected in some way, each eye would see its own parallelogram leaning down and toward the opposite side. Instantly a change does take place in both eyes, so that the two together see, not a rectangle nor a parallelogram, but a trapezoid, with the longer side above. A clear understanding of what this

change is and how it is effected may be had by a further study of Plate II. In the right eye is shown a dotted parallelogram *a-b-c-d*, of precisely the same form as the parallelogram image 1-2-3-4; but in the former the upper and lower lines are parallel with the horizontal meridian. In the left eye also is shown a dotted parallelogram *a′-b′-c′-d′*, of the same form as the parallelogram 1′-2′-3′-4′, with its upper and lower lines parallel with the horizontal meridian of this eye. The line *c-b* in the right eye bears throughout the same relation to the macula, the horizontal and vertical meridians of this eye, that the line *c′-b′* does to the same parts of the left eye, and they, therefore, correspond. The greater part of the line *d-a* in the right eye also corresponds with the greater part of the line *d′-a′* in the left eye, the parts of these lines not corresponding being their extremities. But the line *c-d* in the right eye nowhere corresponds with the line *c′-d′* in the left eye, except at the points of beginning above; and the same is true of lines *b-a* and *b′-a′*, in their respective eyes. If the dotted parallelograms could be made to coincide with the parallelogram images, the result would be that the two eyes together would see the figure *a-b-c-d′*, a trapezoid, with the longer side above. How this is effected is shown in Plate III., where each eye has been revolved on its visual axis by its superior oblique muscle, so that the horizontal meridian is made

parallel with the upper and lower borders of the parallelogram image; and thus, as far as possible, corresponding parts of the two retinas are brought under the two dissimilar images, and the figure seen binocularly is *a-b-c-d'*. The part of this trapezoid seen in common by the two eyes is *a'-b-c-d*, the part seen by the right eye alone is *a-b-a'*, and that seen by the left eye alone is *d-c-d'*. As will be seen, the law of corresponding points has so modified the law of projection that the visual lines no longer have a common crossing point. This is anarchy, so far as projection is concerned, in these eyes.

When the law of direction is interfered with, as a result of the conflict between it and the more imperious law of corresponding retinal points, the object seen is always in the position that it would have been in, had the images primarily fallen on the parts of the two retinas that have been rotated under them, in obedience to the supreme law of binocular single vision—the law of corresponding retinal points. The displaced images, as a result of either natural or artificial means, cover areas of the two retinas that do not correspond. In order to have binocular single vision, retinal areas that more nearly correspond, and are of the same shape and size as the images, must be brought under them. The object will be seen as though no rotation had taken place, as if the images had primarily fallen on these parts, in perfect obe-

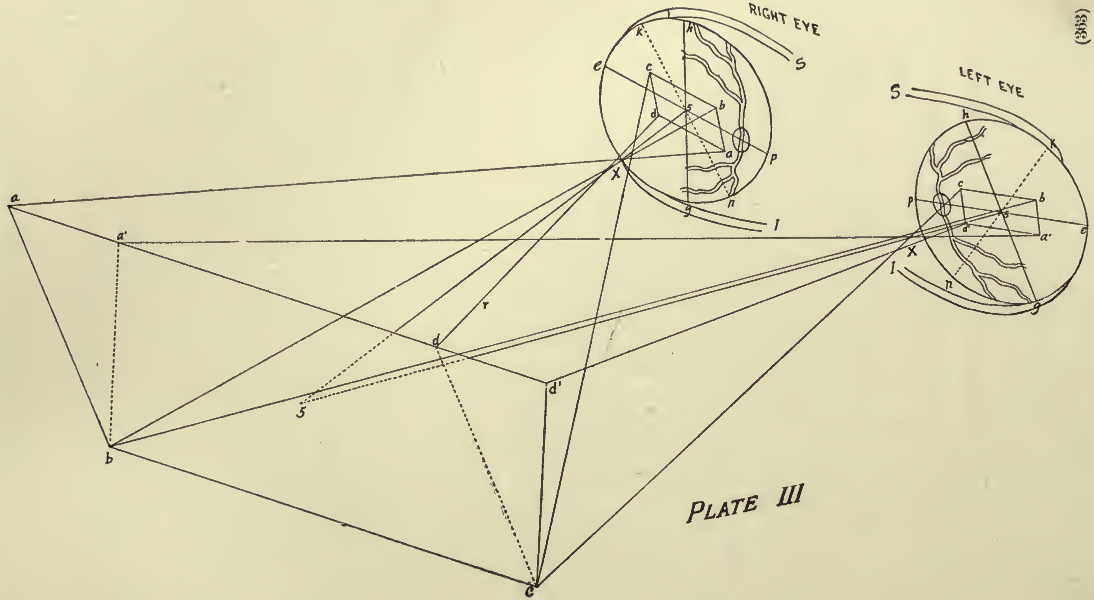

PLATE III

dience to the law of projection, although the lines of direction drawn from the images to the single object will not cross at the center of retinal curvature. In cases of decentration of the maculas, and in displaced images by means of prisms, all lines of direction will cross at one point, but that point will be above, below, to the outer or inner side of the true point; while in oblique astigmatism, and when the axes of correcting cylinders are displaced, no three lines of direction cross at the same point.

In like manner a plate could be made showing how astigmatic eyes, with meridians of greatest curvature converging above, would see a rectangle distorted into a trapezoid, the longer side below. In each eye there would be a parallelogram image inclining down and out. To fuse these into a trapezoid, the inferior oblique muscles would be brought into action, in order, as far as possible, to bring corresponding retinal parts under dissimilar images, which is done the moment the obliques displace the horizontal meridians so that they become parallel with the upper and lower borders of the distorted images.

Imperfect as is binocular single vision in uncorrected oblique astigmatism, the meridians of greatest curvature either diverging or converging above, it could be effected in no other way than by a revolution of the eyes by the symmetric harmonious action of the oblique muscles. It

is true that Nature has one other method of preventing diplopia—namely, mental suppression of one of the displaced images. It may be that amblyopia resulting from oblique astigmatism high in degree, and from insufficiency of the obliques, is more common than one would at first think. Certainly, if the obliques cannot do their proper work in effecting binocular single vision, in the first years of life, nothing is more reasonable than to suppose that amblyopia *ex anopsia* would develop. Who has not seen cases of amblyopia without being able to account for it?

The phenomena outlined can be demonstrated experimentally by any one who desires to prove all things; for he can produce in his own case, at pleasure, any form of astigmatism. But some may be ready to say that artificial astigmatism is one thing and natural astigmatism is another thing. This is true, but only in name. That 3 D of artificial hyperopic astigmatism is the same error of refraction as 3 D of natural hyperopic astigmatism is abundantly proved by the fact that each is thoroughly corrected by a plus 3 cylinder, axis properly placed. Either plus or minus cylinders may be used in the experiments, for the one is as capable of producing artificial astigmatism as the other. If the plus cylinders (3 D) be used, the astigmatism produced has its meridian of greatest curvature at right angles to the axis of the

cylinder, while the meridian of greatest curvature would correspond with the axis of the minus cylinder (3 D) if it were used.

By either means it can be easily proved that in astigmatism of any kind (myopic, hyperopic, or mixed), whose meridians of greatest curvature diverge above, there is a necessity for action on the part of the superior oblique muscles in order to prevent diplopia. This action, having its beginning in the earliest days of infancy and continuing during waking hours until the cause is corrected or one eye is lost, converges the naturally vertical axes above. If the meridians of greatest curvature converge above, the images of all objects are so displaced in the two eyes as to throw into activity the inferior obliques, so that diplopia may be prevented.

In astigmatism with the principal meridians vertical and horizontal, the only eye muscles brought into action to remedy, in any way, the condition, are the ciliary muscles. In oblique astigmatism with the meridians of greatest curvature diverging above, there is the same state of ciliary strain to sharpen as much as possible the images, and there is also a necessary activity of the superior obliques so as to bring corresponding parts of the two retinas under the oblique images, that there may be binocular single vision. Again, in oblique astigmatism with the meridians of greatest curvature converging

above, there is the ciliary strain for sharpening the images, and there is also a consequent activity of the inferior obliques so as to bring similar parts of the retinas under the dissimilar images, resulting in binocular single vision.

When there is equality of strength of the obliques of the two eyes, vertical and horizontal astigmatism will give less trouble than when the astigmatism is oblique in either direction, and astigmatism with the meridians of greatest curvature diverging above need give no more annoyance to the patient than if these meridians converged above; for, in the former case, the superior obliques would be as able to bear the strain as would the inferior obliques in the latter condition.

But the obliques are not always harmonious: the superior obliques are insufficient in at least twenty-five per cent of all cases, while the inferior obliques are insufficient in less than one per cent of all cases. In cases of insufficiency of the superior obliques, the vertical form of astigmatism would be worse on the patient than if he had oblique astigmatism with the meridians of greatest curvature converging above; and the worst form of astigmatism would be that in which the meridians of greatest curvature diverge above. The reverse would be true if the inferior obliques were insufficient—a rare condition.

The complicated function of the oblique muscles exists only in cases of oblique astigmatism with the meridians of greatest curvature converging or diverging above, and in unequal degrees of oblique astigmatism when the meridians of greatest curvature are parallel. The necessity for this function is entirely destroyed when the astigmatism is properly corrected; but the action of the obliques does not always cease at once in binocular single vision through the correcting cylinders. The old habit of rotation often continues for hours, and sometimes for days (although there is no longer a need for it), and the result is metamorphopsia. Inherent weakness of the superior oblique muscles, in a large per cent of the cases, leads to a more speedy disappearance of the metamorphopsia when the meridians of greatest curvature diverge above than when they converge. The reverse would be true in a case of insufficiency of the inferior obliques. The *habit* of action is more quickly suspended in a weak muscle than in a strong one. In all cases, however, it ceases, and the metamorphopsia vanishes, under the continuous wearing of the correcting cylinders.

A careful study of what precedes in this chapter will show that, while the superior obliques must fuse the displaced images of a horizontal line, in cases of astigmatism with the meridians of greatest curvature diverging above, the inferior obliques must fuse the displaced

images of a vertical line, in the same kind of cases. When the meridians of greatest curvature converge above, the displaced images of a horizontal line must be fused by the inferior obliques, while the displaced images of a vertical line would be fused by action of the superior obliques. In most cases of oblique astigmatism the inferior obliques can fuse images more easily than the superior obliques, for the reason that the former are usually stronger than the latter; but when a figure consists of both vertical and horizontal lines, such as a rectangle, the upper and lower borders, respectively, of the images must be fused, whether by the inferior obliques or the superior obliques. The lateral borders—the vertical ends of the rectangle—become divergent above if the fusion has been effected by the superior obliques, while they become divergent below if the fusion has been effected by the inferior obliques. There is no known reason for the fusion of the upper and lower borders of images to the detriment of the lateral borders, and it may remain always an unexplainable fact.

The extent of displacement of images of horizontal lines by oblique astigmatism can be measured only by the cyclo-phorometer, but this measurement cannot be accurately made if there is a complicating cyclophoria. If the meridians of greatest curvature diverge above and there is a complicating plus cyclophoria, the measure-

ment will show greater displacement than really exists; while the measurement will show less than the real displacement when the meridians of greatest curvature converge above and there is a complicating plus cyclophoria.

In measuring the displacement of the image by oblique astigmatism, the single Maddox rod must be used, in the cyclophrometer, and the vertical displacing prism must be behind one rod so as to make one streak of light below the other. The axis of each rod should be vertical. Both eyes having oblique astigmatism, the meridians of greatest curvature diverging above, each streak of light will dip toward the opposite side. Revolving one rod until the two streaks are parallel, though not horizontal, shows the sum of the displacement of the two images; while revolving each rod until the two streaks are horizontal, therefore parallel, the extent of displacement of the image in each eye is easily read on the scale. This shows, also, the amount of minus cyclotropia necessary for the fusion of the two images of a horizontal line. The degree of displacement of the image of a horizontal line depends on both the quantity of the astigmatism and the extent of the obliquity of the meridian of greatest curvature up to 45° from the vertical, at which point there is the maximum of displacement. The compensating cyclotropia of the two eyes always equals the sum of the displacements of the two images.

The apparent dipping of the streak of light due to cyclophoria may be differentiated from that caused by oblique astigmatism by substituting the triple rod for the simple rod. With the triple rod the dipping line of cyclophoria will be unbroken, while the dipping line of oblique astigmatism will be broken into as many parts as there are rods, the one part slightly over-riding the other in the direction of the obliquity of the most-curved meridian.

This obliquity of the image varies from a few minutes to a few degrees, but is always enough, even in slight cases of oblique astigmatism, to force the obliques to disturb the parallelism of the vertical axes with the median plane of the head. Persons with oblique astigmatism, with the meridians of greatest curvature converging or diverging above, cannot have correct ideas of direction, except in line of the visual axes, nor can they judge correctly of verticality, horizontality, and goniometry.

The abnormal work required of the obliques because of oblique astigmatism (non-parallel) develops symptoms not unlike those caused by cyclophoria.

Treatment.

The treatment of compensating cyclotropia is always non-surgical. The careful correction of the astigmatism

will counteract the distortion of the retinal images and relieve the cyclotropia, but not at once; the lifetime habit of the obliques cannot be broken at once; but sooner or later these muscles will learn that, under the new condition (the wearing of the correcting cylinders), they must parallel the vertical axes of the eyes with the median plane of the head, in order to satisfy the law of corresponding retinal points.

In all cases of astigmatism, one eye looking through its correcting cylinder will see at once a rectangle as a rectangle; and if the meridians of greatest curvature are parallel—whether vertical, horizontal, or oblique—the two eyes looking through the cylinders will show no distortion of a rectangular figure. The reason for this is that, in such cases, the obliques have never done other work than the keeping of the vertical axes of the eyes parallel with the median plane of the head; therefore they have no habit to break when cylinders are given. In such cases the glasses are worn with gladness from the beginning.

There is always metamorphopsia to annoy a patient whose astigmatism was such that the meridians of greatest curvature diverged above, when she begins the wearing of correcting cylinders, whether they be plus or minus. This distortion is easily noticed, for it is the opposite of that to which she has always been accustomed

and which she may never have noticed. Seen through the correcting cylinders, a rectangle will appear as a a trapezoid, with the longer side below; a level surface will slant toward her; and a vertical object will lean toward her. The metamorphopsia is due to the fact that the superior obliques, always in the habit of converging the vertical axes of the eyes in binocular vision, continue to thus converge them for a time, so that the axis of the plus cylinder and the meridian of greatest curvature do not remain in the same plane. The superior obliques, possibly because they are usually weaker than the inferior obliques, readily break from their old habit, and the metamorphopsia vanishes. In such cases it is a question of only a few hours—or, at most, a few days—until the correcting cylinders can be worn without annoyance of any kind. The old habit broken, the meridian of greatest curvature (least if a minus cylinder is used) and the axis of the cylinder lie in the same plane in binocular as well as in monocular vision.

When the meridians of greatest curvature converge above, the wearing of the cylinders will be attended by metamorphopsia for a much longer time, possibly because the inferior obliques, being stronger than the superior obliques, are less inclined to give up the old habit of diverging the vertical axes of the eyes, in the act of binocular vision. With either eye alone, a rectangle,

seen through the correcting cylinder, will be a rectangle; the floor will appear level, and a vertical object will not be inclined. In binocular vision through the cylinders a rectangle will appear as a trapezoid, with its longer side above; a level surface will slant from the patient; and a vertical object will lean from her. These appearances, being new, will be easily noticed, and will often prove very annoying to the patient, unless previously told about them. Finally, the old habit of rotation will cease, and the metamorphopsia will disappear, but only after days or weeks of constant wearing of the cylinders.

After the disappearance of the metamorphopsia, caused by plus cylinders, whose axes diverge above, on raising the lenses a rectangle will appear as a trapezoid, with the longer side above; but if the axes of the cylinders converge above, on raising the lenses a rectangle will appear as a trapezoid, with the longer side below. The same changes in the rectangle existed before the cylinders were ever prescribed, but they were unnoticed. Now that the cylinders have corrected the misshaped images, giving perfect vision, on raising the lenses the misshaped images at once make the patient conscious of the distortion of the object.

There are two methods of dealing with cases of non-parallel oblique astigmatism so as to shorten the annoy-

ing period of habit-breaking on the part of the oblique muscles. One method was suggested by Lippincott, of Pittsburg, Pa. He advises that the full error be determined under a mydriatic, and that the exact location of the principal meridians be found, which can be easily done, if the compensating cyclotropia is not complicated by a cyclophoria, by excluding one eye while testing the other; for then the one eye assumes that position which makes its vertical axis parallel with the median plane of the head. The findings, both as to strength of cylinders and positions of axes, are to be recorded. At first the cylinders given should be one-third the full strength required, but their axes must be placed according to the record. When the little metamorphopsia caused by the partial correction has disappeared, new cylinders of two-thirds the required strength are given. The little metamorphopsia caused by these, having vanished, the full correction is given. These cause but slight metamorphopsia, and that for only a short while.

This method is more necessary and more helpful when the meridians of greatest curvature converge above, and consequently when the inferior obliques are the muscles involved. A full correction of the astigmatism at once corrects the shape of the images, so as to make them correspond with the object. These images would now

fall on corresponding retinal points if the vertical axes of the eyes were made parallel with the median plane of the head. To thus relate the vertical axes, the inferior obliques must cease their efforts to diverge them, and the superior obliques must assume the labor of paralleling them. Work must be transferred from the inferior obliques (usually stronger) to the superior obliques (usually weaker). The whole load cannot be shifted at once; and as long as the inferior obliques continue to diverge the vertical axes, so long will the metamorphopsia remain. Righting the images one-third transfers one-third of the work from the inferior obliques to the superior obliques. This small load is kindly and quickly accepted by the superior obliques. The next step rights the images two-thirds, and transfers another one-third of the work from the inferior obliques to the superior obliques. Having become accustomed to the first transference, the superior obliques kindly take on the newly added load. The next step fully corrects the misshaped images, and transfers the balance of the abnormal work from the inferior obliques, in the shape of normal work to the superior obliques. Having already become accustomed to doing two-thirds of the work necessary for paralleling the vertical axes of the eyes, the superior obliques readily assume the remaining one-third of the load that they must now carry. For this class of astigmatics

the Lippincott plan is a good one. The only objection to the method is the cost of changing the lenses.

There is nothing to contraindicate the giving of the full correction, at once, of astigmatism in which the meridians of greatest curvature are parallel, whether vertical, horizontal, or oblique; for, in these cases, the oblique muscles have done the same work without the correcting cylinders that they must do when these are given.

In only high degrees of oblique astigmatism, with the meridians of greatest curvature diverging above, will it be necessary to adopt the Lippincott plan; for, as a rule, the weak superior obliques are ready enough to cease doing the work of converging the vertical axes of the eyes, while the inferior obliques just as readily assume the new duty of paralleling these axes. In all cases, as soon as the obliques learn to parallel the vertical axes of the eyes with the median plane of the head, just that quickly does metamorphopsia vanish.

The other method of correcting oblique astigmatism so that there shall be but little annoyance from metamorphopsia is to give at once the cylinders that fully correct the errors, and to have each lens cut so that, placed straight in the frame, its axis shall be in a plane with the meridian of greatest curvature (least curvature if the lens is a minus cylinder) when the vertical axis of

the eye is parallel with the median plane of the head. However, these lenses must not be placed in their final positions in the rims at first, but each must have its axis rotated into the arc of distortion for the obliques that have been accustomed to doing abnormal work. The rule formulated by Dr. N. C. Steele, of Chattanooga, Tenn., for the placing of the axes of cylinders in oblique astigmatism, is a good one to follow temporarily under certain conditions. His rule, as applied to plus cylinders, is as follows:

"In those cases in which the axes of the proper convex cylinders for the two eyes diverge, place the cylinders in those positions which will give the axes the greatest divergence permitted by the tests; and in those cases in which the axes converge, place them at the points which will give them the greatest convergence permitted by the tests."

The Steele rule for placing the axes of plus cylinders is applicable only when these axes are within 45° of the vertical. Above the 45° point the shifting of these axes should be from the vertical; below the 45° point the shifting should be from the horizontal. In every case of oblique astigmatism with the meridians of greatest curvature diverging or converging above, the axes of plus cylinders should be displaced toward the center of the quadrants in which they are found, and the axes of

minus cylinders should be shifted from the center of the quadrants in which they are found.

The shifting should be only enough to counteract the metamorphopsia, and should be the same for the two cylinders. Every two or three days these axes should be turned a degree or two toward the location determined in the monocular test. With each turning the metamorphopsia will be so little as hardly to be noticed; and finally, when the cylinders are properly located, there is no metamorphopsia. As the result of each backward turning of the axes of the cylinders, the obliques more nearly parallel the vertical axes of the eyes; and when the last turn has been made, the vertical axes of the eyes stand parallel with the median plane of the head.

As the Lippincott method is specially applicable to those cases of astigmatism in which the meridians of greatest curvature converge above, so is it with the rotation method. When the meridians of greatest curvature diverge above—whether the astigmatism be hyperopic, myopic, or mixed, unless high in degree—the full correction should be given at once, and the axes should be placed in the positions determined by the monocular tests.

If the Lippincott method be resorted to, full acuity of vision is not obtained until the full correction of the astigmatism has been given; in the method of rotating

the full-strength cylinders, vision is more or less blurred until the axes are placed at last in their final positions. As to acuteness of vision, the one method has no advantage over the other, and there is just as little annoying metamorphopsia in the one method as in the other.

It is almost universally true that astigmatics whose meridians of greatest curvature diverge above, become speedily accustomed to the correcting cylinders, for the reason that insufficiency of the inferior obliques is so rare—probably not found in more than one case in two hundred. There are some astigmatics whose meridians of greatest curvature converge above, who can never wear comfortably the correcting cylinders because of insufficiency of the superior obliques, which exists in about twenty-five per cent of all cases.

There are three reasons why the arcs of distortion, by cylinders, for the oblique muscles, should be studied: (1) That the operator may know how to place cylinders that they may give rest to the weaker obliques in cyclophoria; (2) that he may know how to shift the cylinders for oblique astigmatics so as to lessen the annoyance from metamorphopsia; (3) that he may appreciate the importance of having the frames, containing the cylinders that correct any kind of astigmatism, so shaped as to set perfectly straight before the eyes.

Several curious facts may be brought forward here,

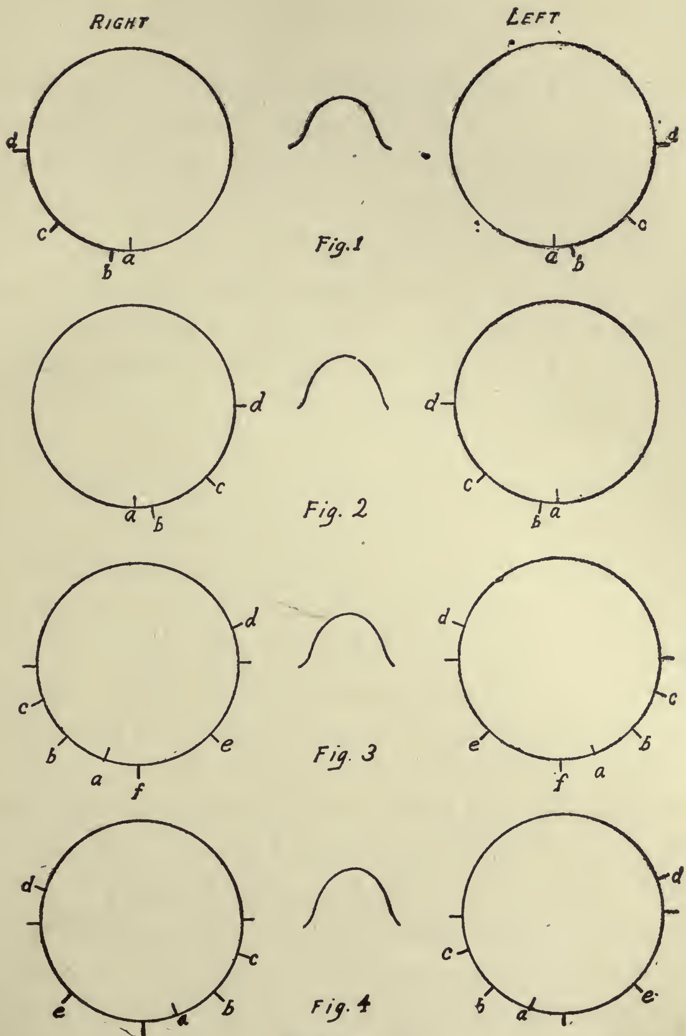

PLATE IV

and reasons have been given why advantage should be temporarily taken of these facts in certain cases. Fig. 1, in Plate IV., represents a pair of hyperopic astigmatic eyes, the meridians of greatest curvature being vertical in each eye. The plus cylinders—axes, 90° (*a*)—insure against strain of either the superior obliques or the inferior obliques; but let the glasses be turned in their rims so that the axis of the right shall stand at 80° (*b*) and the axis of the left at 100° (*b*), images will be distorted, as shown in Plate II., which would necessitate strain on the part of the superior oblique muscles. The distortion of the images would increase, and the strain on the superior obliques would be greater, as the axes are revolved farther away from the vertical, the maximum being reached at 45° (*c*) for the right eye and 135° (*c*) for the left eye. Passing these points, the distortion grows less, until at 180° (*d*) for each eye. it disappears.

Fig. 2 represents the same pair of eyes. If now the axis of the right cylinder should be revolved from 90° (*a*) to 100° (*b*) and that of the left cylinder from 90° (*a*) to 80° (*b*), the distortion of images would be such as to call into activity the inferior obliques, so that there might be binocular single vision. This distortion would reach its maximum when the axis of the right cylinder stands at 135° (*c*) and that of the left cylinder at 45° (*c*), again les-

sening as the axes are made to approach the horizontal, where the distortion ceases.

Fig. 3, Plate IV., represents a pair of hypermetropic astigmatic eyes with the meridian of greatest curvature of the right at 70° (*a*) and that of the left at 110° (*a*). (In all the figures of Plate IV., Plate V., and Plate VI., the mark within the circle shows the location of the meridian of greatest curvature.) These meridians, converging above, would cause strain of the inferior obliques, which would be relieved by the correcting cylinders, axis of the right at 70° (*a*) and of the left at 110° (*a*). A revolution of the axis of the right cylinder to 45° (*b*) and that of the left cylinder to 135° (*b*) would so displace the images as to call into action the superior obliques, the displacement increasing as the axes are moved until these points (*b* for each eye) are reached. Continuing the revolution of the cylinders in the same directions, the displacement lessens, and disappears entirely when the axis of the right reaches 20° (*c*) and that of the left reaches 160° (*c*), when the necessity for over-action of the obliques no longer exists. If the axes of the cylinders are moved from their correct positions (70° for the right eye and 110° for the left eye) to 90° (*f*) for each eye, images will be so displaced as to call into compensating activity the inferior obliques. The maximum of displacement would be effected when the axis reaches 135° (*e*) in the right

eye and 45° (*e*) in the left eye. Continuing the revolution in the same directions, the displacement would grow less, and finally disappear when the axis of the right eye stands at *d*, and that of the left eye at *d*, each 20° above the horizontal. As will be seen, the arc of distortion, so as to throw strain on the superior obliques, is 50° (from 70° to 20° in the right eye and from 110° to 160° in the left eye), while the arc of distortion that would throw strain on the inferior obliques is 130° (from *a* to *d*).

Fig. 4, Plate IV., shows the meridians of greatest curvature of these hypermetropic astigmatic eyes at 110° (*a*) for the right and 70° (*a*) for the left. These meridians, diverging above, would call into compensating activity the superior oblique muscles. Correctly chosen and properly placed cylinders, by correcting the distortion of the images, would remove the necessity for the performance of the complicated function of the superior obliques. Displacing the axes of these cylinders, the right to 135° (*b*) and the left to 45° (*b*), would cause a maximum of distortion of the images, of the kind to call into action the inferior obliques. Continuing the revolution of the cylinders, the distortion would disappear when the axis of the right reaches 160° (*c*) and that of the left reaches 20° (*c*). Should the axes of the cylinders be revolved from their proper places—at 110° (*a*) in the right and 70° (*a*) in the left—to 90° (*f*) for each eye, the

images would be so changed as to call into harmonious activity the superior obliques. The maximum distortion would occur when the axis of the right is at 45° (*e*) and that of the left at 135° (*e*). Continuing the revolution, the distortion would disappear when the axes reach the points *d* above the horizontal meridians. In this case the arc of distortion causing activity of the inferior obliques is 50° (from *a* to *c*), while the arc of distortion that would throw strain on the superior obliques is 130° (from *a* to *d*). If in this pair of eyes the meridians of greatest curvature had been at 130° for the right and 50° for the left, the arc of distortion that would call the inferior obliques into action would be only 10°, while the one that would cause activity of the superior obliques would be 170° (180° less 10°).

Fig. 1, Plate V., represents hypermetropic astigmatic eyes, the meridians of greatest curvature being at 180° (*a*) in each eye—a condition that, in itself, would not call either the superior obliques or the inferior obliques into activity. The correct plus cylinders—axes, 180°—would sharpen the blurred, but not distorted, images. Displacing these axes in the lower temporal quadrants would so distort the images as to throw into action the superior obliques; and the maximum of distortion would be effected when the axes reached 45° (*c*) in the right eye and 135° (*c*) in the left eye. With the axes turned to 90° (*d*), there

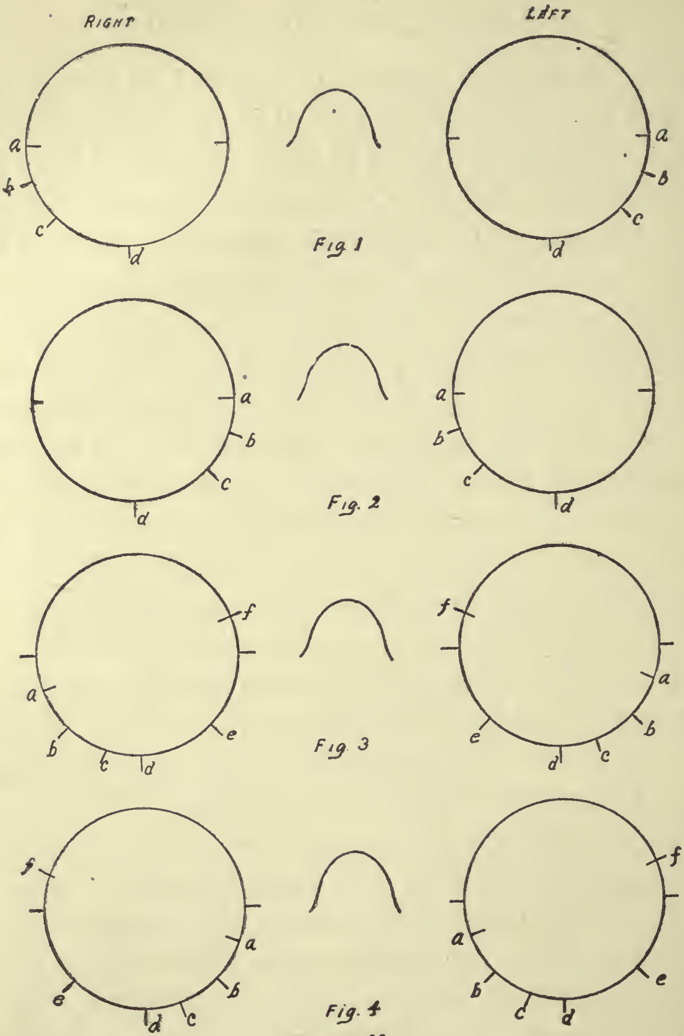

PLATE V.

would be no distortion of images, though there would be blurring, as in all cases of displaced cylinders.

Fig. 2, Plate V., represents the same pair of eyes shown in Fig. 1. Revolving the axes of the correcting cylinders in the lower nasal quadrant, would so distort images as to call into action the inferior oblique muscles, the maximum being effected when the axes stand at 135° (*c*) for the right eye and 45° (*c*) for the left eye, the distortion lessening as the axes approach, and disappearing altogether when they reach, 90° (*d*).

A comparative study of Fig. 1 and Fig. 2 of Plate IV., with Fig. 1 and Fig. 2 of Plate V., will show that, in hypermetropic astigmatism with the meridians of greatest curvature either vertical or horizontal, a revolution of the axes of the cylinders in the lower temporal quadrant will distort images (as of a rectangle) down and in, and will thus call into harmonious action the superior obliques; and it will also show that a revolution of the cylinders in the lower nasal quadrants will so displace the images as to call into harmonious action the inferior obliques.

Fig. 3, Plate V., represents a pair of hypermetropic astigmatic eyes with the meridian of greatest curvature for the right eye at 20° (*a*) and that of the left eye at 160° (*a*). Since these meridians converge above, the uncorrected condition would cause harmonious action of the

inferior obliques. Properly chosen and correctly placed cylinders, axes at 20° (*a*) for the right eye and 160° (*a*) for the left eye, would relieve the distortion of the images and do away with the necessity for the compensating action of the obliques. Revolving the axis of the right cylinder from 20° (*a*) to 45° (*b*) and that of the left cylinder from 160° (*a*) to 135° (*b*) would cause a maximum displacement of images in such a way as to call into action the superior oblique muscles, the distortion disappearing when these axes reach 70° (*c*) for the right eye and 110° (*c*) for the left eye. Passing 70° (*c*) in the right eye and 110° (*c*) in the left eye, the distortion becomes reversed, so that the strain will be thrown on the inferior obliques, the maximum being attained when the axis of the right stands at 135° (*e*) and that of the left at 45° (*e*). The distortion decreases as the axes are still farther turned in the same directions, and disappears at the end of the arc of 130° (from *c* to *f*) when they coincide with the meridians of greatest curvature. Thus the arc of distortion involving the superior obliques is 50° (from *a* to *c*), while that involving the inferior obliques is 130° (from *c* to *f*).

The eyes (hypermetropic astigmatic) represented by Fig. 4, Plate V., have their meridians of greatest curvature at 160° (*a*) in the right and 20° (*a*) in the left. These meridians diverging above would result, in the

uncorrected case, in calling into harmonious action the superior obliques. Proper cylinders with the axis of the right at 160° (*a*) and that of the left at 20° (*a*) would correct the distortion of the images and relieve the strain on the superior obliques. A turning of these cylinders in the arcs *a-c* would distort the retinal images so as to bring into action the inferior oblique muscles, the maximum distortion existing when the axes are at *b*. Continuing the revolution from *c*, the distortion becomes reversed, and, as a consequence, the superior obliques are brought into activity, the maximum being attained when the axes reach *e*. As the axes are revolved farther, the distortion lessens, and finally disappears when they stand at *f*, again coinciding with the meridians of greatest curvature. In this pair of eyes the arc of distortion involving the inferior obliques is 50° (from *a* to *c*), while that involving the superior obliques is 130°, the maximum of distortion in both instances being attained when the halfway point of the arc is reached by the axis of the cylinder.

A comparative study of any two, or all, of the figures in Plate IV. and Plate V., will show that the arc of distortion, by corrective plus cylinders, involving the superior obliques, is always in the lower temporal quadrant, wholly or in greater part; and if entirely within this quadrant, its length is always twice the distance from

the meridian of greatest curvature to the 45° point of the quadrant, the other half being on the opposite side of the latter. In like manner it will be seen that the arc of distortion involving the inferior obliques, by a revolution of plus cylinders, is always in the lower nasal quadrant, wholly or in greater part; and if entirely within the quadrant, its length is twice the distance from the meridian of greatest curvature to the 45° point of the quadrant, the other half being on the opposite side of the latter. When the arc of distortion involving the superior obliques is 90°, that involving the inferior obliques is 90°, and *vice versa;* when the arc of distortion involving the superior obliques is less than 90°, the arc involving the inferior obliques is always the difference between the former and 180°, and *vice versa.* The maximum of distortion is always attained when the axis of the cylinder is at the halfway point of the arc.

Fig. 1, Plate VI., represents a pair of hypermetropic astigmatic eyes, the meridian of greatest curvature of the right eye at 45° (*a*) and that of the left eye at 135° (*a*). These meridians converging above would cause such distortion of images as to throw into harmonious action the inferior oblique muscles. The proper cylinders, correctly placed—the axis of the right at 45° (*a*) and the axis of the left at 135° (*a*)—would counteract the distortion and relieve the inferior obliques of the necessity of over-

acting. Revolving the axes of the correcting cylinders in either direction would so distort images as to call into harmonious action the inferior oblique muscles. Since the arc of distortion for the superior obliques in this case is nothing, the arc of distortion for the inferior

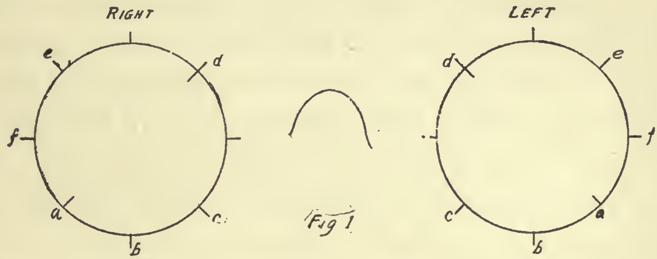

Fig 1

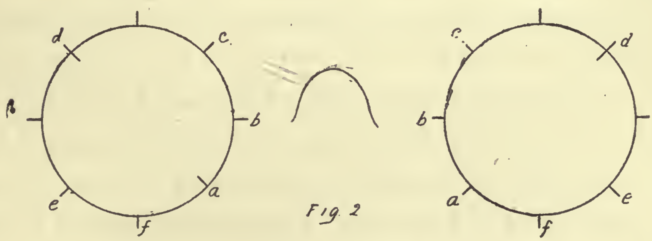

Fig. 2

PLATE VI.

obliques is 180°, from *a* to *d* in either direction, the maximum of distortion being attained, respectively, at *e* above and at *c* below.

Fig. 2, Plate VI., represents a pair of the same kind of eyes, but with the meridian of greatest curvature at 135° (*a*) for the right eye and 45° (*a*) for the left eye. These

meridians diverging above, the refraction is such as to distort images so as to call into harmonious action the superior obliques. As in the other case, the correct cylinders, properly placed, counteract the distortion and relieve the superior obliques from action. Rotating the axes of these cylinders in either direction from *a* would so distort images as to call into activity the superior obliques. In this case the arc of distortion for the inferior obliques is nothing, and, therefore, the arc of distortion for the superior obliques is 180°, from *a* to *d* in either direction, the maximum being attained at *c* above and at *e* below.

In the adjustment of cylinders for the correction of astigmatism—whether it be vertical, horizontal, or oblique—a knowledge of the arcs of distortion by displaced cylinders is of great importance. Patients should be impressed with the absolute necessity of keeping the rims containing the glasses in such relationship to each other that a straight edge would pass through the following four points: the two points where the temple pieces join the rims and the two points of attachment of the nose bridge to the rims. If the frames should be so bent that the long axis of each lens would lean down and out, and the astigmatism is according to the rule, the cylinders would be displaced in the arc of distortion for the inferior obliques, which, usually, would be borne

fairly well; but when the astigmatism is against the rule, this displacement would be in the arc of distortion for the superior obliques, and would cause much annoyance. This would be true, whether the astigmatism were hyperopic, myopic, or mixed.

If the frames should be so bent that the long axes of the lenses pointed down and in, the astigmatism being according to the rule, the axes of the cylinders would be displaced in the arcs of distortion for the superior obliques, and would cause trouble; but if the astigmatism were against the rule, the displaced axes would be in the arcs of distortion for the inferior obliques, and but little trouble would result unless the displacement should be considerable.

If the frames are so shaped that the long axis of each lens lies in the same plane with the long axis of the other, the leaning of the common plane down and to the right, resulting from a bend upward of the temple piece on the corresponding side, or a bend downward of the temple piece on the opposite side, the cylinders being of equal strength, no strain of the obliques will be excited, for the reason that the distortion in the one eye would be similar to the distortion in the other. Vision would be blurred and all objects would appear out of their proper places. The ciliary muscles might make an attempt to sharpen the images, but there would

be no necessity for the obliques to make an effort either to diverge or converge the vertical axes of the eyes in order that there might be fusion of the displaced images. The same would be true if the straight frames were made to incline down and to the left. Bent frames are capable of doing more or less harm through abnormal excitation of the brain-centers controlling the oblique muscles.

Spectacle frames should be given astigmatics, for the reason that they can be much better adapted to the face than the most perfect-fitting nose-glass frames that have ever been invented.

A knowledge of the character of distortion of retinal images, by oblique corneal astigmatism, enables the operator to tell the patient beforehand just the kind of metamorphopsia that will result from the wearing of the correcting cylinders, and whether it will soon vanish or be a long time in disappearing.

CHAPTER IX.

COMPENSATING LATERAL AND VERTICAL HETEROTROPIA.

THE recti muscles may be perfectly developed, their attachments may be ideal, and their innervation centers may be faultless; nevertheless, if there is any form of anisometropia, there must be some form of heterotropia whenever the visual lines are made to sweep from the primary point to some other point of view. If the right eye is emmetropic and the left eye is hyperopic, the image of a square will be larger in the former than in the latter. When the point of fixation is the center of the square, the recti will have the visual axes in the same plane and will cause them to intersect at the point of view. If the point of view is to be changed from the center of the square upward, so as to fuse the upper border, it becomes evident that the visual axis of the right eye must rise higher than the visual axis of the left eye. Without this compensating hypertropia these borders could not be fused. Again, if the point of view is to be changed from the center of the square down-

ward, so as to fuse the lower border, the visual axis of the emmetropic eye must travel farther than that of the hyperopic eye in order to fuse the lower borders. The cause of the fusion is a compensating catatropia of the emmetropic eye. If the point of view is to be changed from the center of the square to its right border, the visual axis of the right eye must sweep farther to the right than that of the left eye, or the borders cannot be fused. This is accomplished by a compensating exotropia of the right eye. Likewise there must be a compensating esotropia of the right eye, if the point of view must be changed from the center of the square to its left border. All of this is illustrated by Fig. 51, taken from Chapter VIII., in which *a-b-c-d* represents the square as seen by the hyperopic eye, and *a″-b″-c″-d″* represents the square as seen by the emmetropic eye. The distance from *e* to the line *a″-d″* is greater than to the line *a-d*.

The same figure shows that if one eye were emmetropic and the other eye were myopic, the larger square —*a″-b″-c″-d″*—would be seen by the myopic eye, while the smaller square (*a-b-c-d*) would be seen by the emmetropic eye. In such a pair of eyes the compensating heterotropia would be confined to the myopic eye.

Again referring to the same figure, if one eye had myopic astigmatism, the meridian of greatest curvature

vertical, it would see the square as a'-b'-c'-d', while the other eye, being emmetropic, would see the square as it really is—a-b-c-d. In such eyes there would be no compensating lateral heterotropia, for a-b coincides with a'-b' and d-c coincides with d'-c'; but there will be ver-

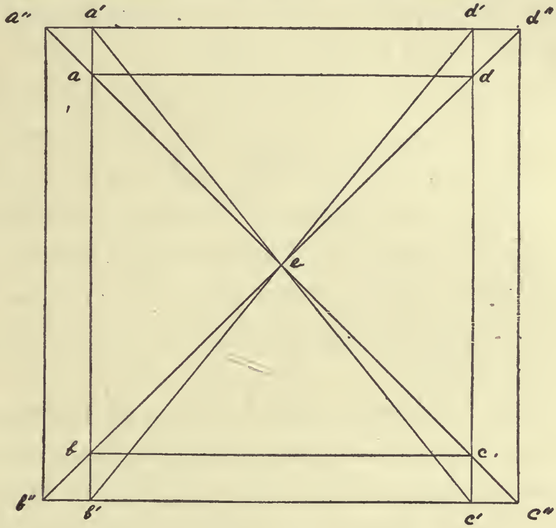

Fig. 51.

tical compensating heterotropia, for the reason that e is nearer a-d and b-c than it is to a'-d' and b'-c'.

In the same way all forms of anisometropia may be studied, showing the necessity for compensating heterotropia on the part of the eye having the greater refractive power, or the eye that is longer.

As compensating cyclotropia is always cured by the application of obliquely-placed cylinders, so compensating lateral and vertical heterotropias are cured by the lenses needed for the correction of the focal errors. It is more necessary to correct unequal refraction, though the errors be not great, than it is to correct greater errors that are equal in the two eyes.

Prisms and lenses rendered prismatic by decentration cause compensating heterotropia in the direction of the apex of the prism; therefore, prisms given for constant wearing to an exophoric, cause compensating exotropia; prisms given to an esophoric develop a compensating esotropia; and a prism placed base down for the relief of a hyperphoria generates a compensating hypertropia of that eye.

In spherical anisometropia the law of direction is interfered with, so far as the eye of greatest refraction is concerned, except when the two eyes are in the primary position. When there is astigmatism of one eye and emmetropia, hyperopia, or myopia of the other, there can be no heterotropia in the direction of that principal meridian of the astigmatic eye which has the same radius of curvature as the non-astigmatic cornea of the other eye; but in the direction of the other meridian there will be compensating heterotropia. In the compensating heterotropia caused by prisms and decentered lenses there is

interference with the law of direction in all parts of the field of view.

Decentered Corneas and Misplaced Maculas.—There are two other causes for compensating vertical and lateral heterotropia. The one is a decentration of the cornea; the other is displacement of the macula. It would probably be more nearly correct to say that there is but one other cause—that is, decentration of the cornea. The antero-posterior axis of the eye, that axis controlled by the recti muscles, which must always be at right angles to the equator of the eye, can be none other than the visual axis. Commencing always at the fovea centralis, it passes always through the center of retinal curvature and thence through the center of an ideally placed cornea; but if the cornea is not properly centered, the visual axis passes through some other part than the center. The posterior pole of the eye, whether near to or far away from the optic disc, or above or below it, is the center of the macula; the anterior pole may or may not be the center of the cornea. In ideal eyes—eyes that see best or can be made to see best—the anterior pole is the center of the cornea. The antero-posterior axis of the eye, as given by anatomists and adopted by writers of books on the eye, has its beginning at the center of the cornea, passes backward through the center of rotation, and strikes the retina, maybe at the macula, but is just as

likely to strike it elsewhere. The error is in giving the anterior pole a fixed location—the center of the cornea. Such an axis can be at right angles to the equator of the eye in which lie the vertical and transverse axes of the eye, only when it coincides with the visual axis. It can be of value only in determining the extent of the decentration of the cornea, or how much the cornea lacks of occupying the ideal position.

In true compensating heterotropia, retinal images on the maculas are either sharp or can be made so; but when there is decentration of the corneas, the rays of light that strike the maculas are never perfectly focused, nor can they be made to focus perfectly by any artificial means. In true compensating heterotropia, that caused by anisometropia, or by prisms, there is interference with the law of direction. This is not true of decentration of the cornea; for the visual axis points directly to the source of the light, although the eye appears to be pointing in some other direction as indicated by the position of the center of the cornea. The heterotropia, then, is apparent, and not real; therefore it cannot be properly called a "compensating heterotropia." The angle *gamma* measures the apparent deviation of the eye and the real displacement of the cornea.

When an eye whose cornea is ideally situated is examined with the Javal ophthalmometer, the reflected

disc will have its center coincide with the center of the cornea; but if the cornea is displaced out, the reflection will be more from the nasal side; if displaced in, the reflection will be in greater part from the temporal side; if displaced down, the greater part of the reflection will be from the upper part of the cornea; and if displaced up, the reflected image will be more below than above. Oblique displacement of the cornea will show an oblique displacement of the reflected image of the ophthalmometer disc. These examinations, to be accurate, must be made while the patient is looking directly into the center of the telescopic tube, and the reflected image must be looked at through the center of the leveling slit above the telescope. A considerable proportion of corneas thus examined will show slight displacements, but rarely more than 5°. When the angle *gamma* is much in excess of 5°, it means that the acuteness of vision cannot be made equal to 20–20.

The various forms of heterophoria, and anyone of the true heterotropias, may be found in eyes whose corneas are not properly centered. The former should be dealt with in the manner prescribed in the chapters preceding this one; and the true heterotropias should be treated after the methods to be set forth in the next chapter. For apparent heterotropia nothing can be done; so, therefore, nothing should be attempted. In operating for the

relief of true heterotropia, it should be known whether or not there is a false heterotropia as well, else the treatment might result disastrously.

The new-formed physiologic macula that some think they have found in a squinting eye, is the old macula of an eye whose cornea is not correctly placed. There is no part of one eye, save the macula, that can harmonize with the macula of the other. Because of opacities in the refractive media, or because of disease of the choroid behind the macula, a peripheral part of the retina of that eye must be used, but it can never be made a macula; it can never be made to harmonize with the macula of the healthy fellow eye.

CHAPTER X.

HETEROTROPIA.

THE appearance of eyes whose muscles fail to coordinate them, rendering binocular single vision impossible, has been designated by the terms "squint," "strabismus," and "cross-eyes," by both ancient and modern writers. It may be long before these terms can be entirely eliminated, although there is now no good reason for retaining them. "Heterotropia," a term introduced by Stevens, carries its own meaning with it, the plain English of which is a "wrong turning." This term should be preferred, not only because of its simplicity, but also because it is in conformity with the now universally accepted term, "heterophoria," as applied to the muscles whose relationship to each other is such as to render it difficult for them to so relate the eyes as to make binocular vision possible. "Heterotropia" is a generic term, and includes all forms of deviation of the visual axes and the vertical axes of the eyes; "esotropia" means that there is a deviation of the visual axes inward, so that they cross each other between the observer

and the point of observation; "exotropia" means that there is an outward deviation of the visual axes, so that they either cross beyond the point of view or become parallel, or even become divergent; "hypertropia" means that one visual axis is raised above the other, while "catatropia" means that one visual axis is turned below the other; "cyclotropia" means that the vertical axes of the eyes are not kept parallel with the median plane of the head, either diverging from it above (plus cyclotropia) or converging toward it above (minus cyclotropia). One form of heterotropia may be complicated by one or more of the other forms.

As taught in Chapter I. of this book, binocular single vision is possible only when the superior and inferior recti muscles keep the two visual axes in the same plane; when the internal and external recti so control these axes, in that plane, as to make them intersect at the point of view; and when the superior and inferior obliques parallel the vertical axes of the eyes with the median plane of the head. These muscles accomplish this work in obedience to the unalterable law of corresponding retinal points. Disobedience on the part of these muscles develops diplopia, for the reason that the two images of the one object cannot fall on corresponding retinal points. That objects are not always seen double by persons who have any form of heterotropia

can be due to nothing else than mental suppression of one image.

Before entering minutely into the study of heterotropia, it will be interesting to review, briefly, its history. That the condition has existed in every generation from the beginning of the human family, can hardly be doubted. What it was interpreted to mean in ancient times cannot now be known. Hippocrates wrote of the deformity as a thing of inheritance, but sometimes resulting from disease. From the time of his writing, on down through the centuries, there is no evidence of any careful or scientific study of heterotropia until in the second quarter of the nineteenth century. About this time Stromeyer announced that strabismus was due to abnormal contractions of the eye muscles, and that it might be cured by tenotomies. He performed experimental tenotomies on the dead subject to his satisfaction. One year later, in 1839, Dieffenbach operated on his first case of internal squint, dividing the tendon of the internal rectus close to its attachment to the sclera. He thus continued to operate through a lengthy series of cases. Other German surgeons, and surgeons in France and England, began at once to accept the teaching of Stromeyer and to adopt the practice of Dieffenbach. After the French Academy of Sciences had awarded its prize of six thousand francs —half to Stromeyer for conceiving the operation and

demonstrating it on the dead subject, and half to Dieffenbach for having first operated on the living subject by cutting the tendon of the muscle close to its attachment to the sclera—Dieffenbach himself led in the bad practice of cutting the tendon farther back. He reasoned that the farther from the insertion the cut was made, the greater would be the effect, and by this reasoning he was induced, in severe cases, to make the cut through the muscle structure itself. So disastrous were these myotomies, or tenotomies far behind the insertions of the tendons, that the operation for strabismus began to fall into disrepute. It required the master mind of Graefe to check the tide of professional feeling against tenotomies of the recti muscles. His voice called operators back to the original operation of Dieffenbach, after which external squints were less frequently found as a result of operations for internal squint, and once more the operation came into favor. Graefe even went farther in the direction of safety than a simple return to the Dieffenbach original tenotomy, in that he advised partial tenotomies in the slighter cases. He even made marginal tenotomies, but apparently these were done empirically; at any rate, he did not give any reason for doing these marginal operations, other than that the uncut fibers would prevent the muscle from retracting too far. If done empirically, while some of them may have

been helpful, others must have been hurtful, because of the wrong kind of torsioning resulting. It appears that Graefe abandoned marginal tenotomies, possibly because of the unfortunate torsional results that followed in many of his cases. That there is a scientific—and, therefore, sound—basis for marginal tenotomies has already been shown in previous chapters, and will be set forth again, in the proper place, in this chapter. It would also appear that Graefe ceased to do even central partial tenotomies; for, in conversation with Knapp, who was telling him of these operations which, thus early in his professional career, he was doing, he said, "You will not do that long,"* thus indicating that he himself had already abandoned the practice of partial tenotomies. Yet it will be shown in this chapter that partial, and not complete, tenotomies only should be done, even in the higher degrees of heterotropia.

As was natural, soon after Dieffenbach's tenotomy operation on the contracted muscle was introduced, advancement of the relaxed muscle was suggested and practiced by Querin. The author has been unable to learn the exact method he employed, but it must have been very crude and unsatisfactory. A. von Graefe's improvement of Querin's operation is worthy of mention only as a curiosity. The only connection that the ad-

*See Norris and Oliver, Vol. III., page 877.

vancing thread had with the eye was the loop which he passed through the end of the severed tendon; for the two ends of the thread were carried across the cornea and anchored by adhesive plaster to the nose, if the muscle were the externus, and to the temple, if it were the internus, to be advanced. The threads in contact with the cornea occasionally excited suppuration of that structure, and for this reason the operation was abandoned.

The elder Critchett, in 1862, at the Heidelberg Congress, made public his "method of advancement by stitching the tendon forward." This operation as described by Knapp* is attended by unnecessary traumatism, and is not comparable, in simplicity and ease of execution, with the advancement operation described in Chapter III. of this book. The Critchett operation was adopted at once by Graefe, who was glad to substitute it for his own method. It seems not to have been intended by Critchett that this operation should supplant the operation of tenotomy for the cure of heterotropia, but that it should act only as an aid to the tenotomy.

Since 1878 Landolt has been an earnest advocate of advancement of the relaxed muscle, as against tenotomy of the contracted muscle, in all cases of heterotropia, and as the years have gone by his advocacy of advance-

*See Norris and Oliver, Vol. III., pages 871–72.

ment has grown stronger. Except for the greater ease with which a tenotomy is done, as contrasted with the advancement of a muscle, Landolt's voice would have been heard, and to a greater extent would have been heeded. But, strange to say, while Landolt has been opposing with all his might the cutting of the tendons of the ocular muscles, the tenotomists have found, or think they have found, the check ligaments of the recti muscles; and some of them, not content with completely severing the tendon, have dared to reach back with the scissors and cut these checks. That there are connective tissue fibers that extend from these muscles to the walls of the orbit cannot be denied, but they must be concerned more in firmly fixing the bed of fat through which the muscles pass, than with the action of the muscles, by either hindering or helping them. The dissection accomplished in cutting these ligaments can but allow a greater retraction of the divided tendon, which often proved to be too much even before the ligaments were known to exist.

The only important suggestion in connection with complete tenotomies, since Graefe called operators back to the insertion of the tendon, has come from Panas; but even this suggestion does not redeem the operation of complete tenotomy from the condemnation laid upon it by Landolt. Panas stretches the muscle before sever-

ing its tendon. The stretching of the muscle necessarily results in a state of paresis for the time being, and it is probable that it takes days for the recovery to be effected. A paretic muscle when cut is not in a condition to retract far, hence adhesive inflammation has the opportunity to reattach the cut end of the tendon to the sclera only a little way behind the line of its original attachment. Panas' operation is the only safe complete tenotomy that can be done, but it is doubtful if it should ever be done. Words cannot be made strong enough to condemn a complete tenotomy associated with a cutting of the check ligaments. After any complete tenotomy, except the one suggested by Panas, the operator is exceedingly fortunate if, in a few months, he does not find a condition opposite that for which he operated. Even in Panas' operation the risk of limiting the verting power of the muscle is too great; and occasionally, in spite of the paresis caused by the stretching, the muscle will retract too far and an external squint will replace the former internal squint, or *vice versa*.

One of the strange things connected with the study of the ocular muscles, soon after Dieffenbach did his first operation, was the conclusion that the inferior oblique was an advertor of the eye. Certainly its origin, course, and insertion gave no foundation for such a conclusion. Lucas, in his little book on "The Cure of Strabismus,"

published in 1840, says on page 8: "The action of the inferior oblique is to direct the eye upward and inward." That the above reference to the inferior oblique could not have been a typographical error is abundantly shown in other parts of the book. On page 15 the following sentence occurs: "When either eye is drawn outward by the action of the external rectus muscle, the other is directed inward by the action of the inner rectus and inferior oblique muscles."

That the inferior obliques, without being advertors, may cause a condition that becomes an important complication of esotropia, will be shown later in this chapter.

It is not uninteresting to study the work of a quack, John Taylor, who flourished in the first half of the eighteenth century, at least one hundred years before Stromeyer and Dieffenbach. He evidently found the secret of some cases of squint, and it is just as evident that his secret was kept by him and died with him. He wrote a pamphlet, entitled "De Vera Causa Strabismi," which was published in 1738, in which, it is said, he exploited his cures without exposing his method of operating. In traveling from city to city on the continent of Europe, distributing his pamphlet as a means of advertising, he styled himself as "Oculist to George II., of England," whom he probably had never seen; and when

it suited him better, he claimed to be oculist to the Pope.

Taylor was a man of some penetration; but he must have been a man too full of self-interest to give to science and progress the benefit of his insight. He lost his opportunity to build for himself a monument that would have been to his enduring credit, by burying within himself the knowledge on which he based his practice of straightening cross-eyes. He seems not only to have been an oculist, but a general surgeon as well, for he carried about with him a dazzling display of instruments. His methods of secrecy and his disposition toward self-display must have disgusted surgeons of that time, so that they avoided him, just as honorable medical men of to-day feel disgraced when found in company with a quack. It appears, however, that Le-Cat either witnessed an operation or that he had an opportunity to question Taylor, for he says: * "I availed myself of the freedom which he accorded me to inquire the motive for an operation which appeared to me to be absolutely useless, not to say dangerous. He replied that an eye only squinted because the equilibrium between its muscles was destroyed, and that to reëstablish this equilibrium it was only necessary to weaken the

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*See Stevens' address before the Ophthalmological Association, as published in "Annals of Ophthalmology," Vol. VIII., No. 2.

muscle which dominated the others, and this is what he did in cutting one of the nerve filaments which was distributed to this too powerful muscle."

Heuerman, in 1756, wrote: "Taylor has also proposed to cure squinting by the division of the tendon of the superior oblique muscle of the eye." Another writer says that Taylor passed a silk thread through a fold of conjunctiva at the lower-inner part of the globe, and, drawing this fold forward by means of his loop of thread, cut it with a pair of scissors. The location of this conjunctival cut makes it appear possible that, through it, he passed his scissors with the point of one blade in contact with the orbital floor, and sufficiently far backward to include the inferior oblique muscle, which he may have divided by closing the blades of the scissors; or through the opening he may have passed, in a skillful way, one blade of the scissors between the sclera and the tendon of the internus while keeping the other blade between the conjunctiva and the tendon, and thus effected the division of this tendon.

Taylor must have had some cures, whatever may have been the nature of his operation. Simply sealing with plaster the eye not operated upon, for a few days, could not haye effected a cure, unaided. There is no evidence of the existence of a nerve fiber far forward giving to the internus a part of its power; hence it is reasonable

to conclude that he purposely made a misstatement when he told LeCat that his operation was a division of such a fiber. It is very unlikely that any case of internal squint ever had, as an etiological factor, a too strong superior oblique; hence it is not probable that Taylor ever divided this muscle. That a too strong inferior oblique may be an indirect factor in the production of a small per cent of cases of internal squint will be shown farther on; hence it is not unreasonable to suppose that he may have divided this muscle in some of his operations. To have done so when this muscle elevated the eye and torted it outward, while the internus turned it in, would have been helpful, if not entirely corrective. A simple esotropia could not have been thus corrected; so it appears possible that in simple cases he had learned to divide only the internus. Since Taylor left nothing descriptive of the cause (termed by him "*Vera Causa*") of esotropia, and failed to print, either in pamphlet or lay press, anything as to the method of his operation, one can only surmise what he really thought and did. It is certain that a whole century intervened between him and Stromeyer, during which time no advance was made in the practical study of the errors of the ocular muscles.

The author almost feels that he should apologize for making any reference to Taylor, the quack, who deserved contempt while living and oblivion after death.

A more pleasant task presents itself in a brief study of the work of the immortal Donders, who gave so much thought to the etiology of heterotropia. His investigation into the relationship between accommodation and convergence proved conclusively that hyperopia is one of the factors of esotropia. This doctrine is almost universally accepted, and there seems to be absolutely no room for doubting its truthfulness. It must be granted, however, that Donders placed too much emphasis on this potent factor. If hyperopia were even the chief cause of internal squint, the cases demanding operative interference would be few and far between. Hyperopia must occupy a secondary place as a causative factor of esotropia; nevertheless, it is an important place, for a removal of this cause, by the wearing of convex lenses, early in childhood, often will make the other cause or causes inoperative. The world is indebted to Donders for this knowledge, and for acquiring and imparting it he deserves a monument.

Finally, before taking up systematically the study of heterotropia, it may be stated that it has always been a matter of observation that some cases of internal squint became cured without artificial aid. This spontaneous cure came as the patients grew older, and doubtless depended on the fact that the brain-centers controlling the ciliary muscles no longer generated so great an impulse

for these muscles, as, because of association, would have continued to over-excite the centers controlling the interni. The diminished nerve impulse coming to the interni gave the externi a chance to swing the visual axes into positions of harmony. It is not explainable how other forms of heterotropia could ever recover spontaneously, and it is doubtful if they ever have thus recovered.

As early as the seventh century of the Christian era an appliance was devised for straightening cross-eyes. It consisted of a mask with a hole in it for each eye, which the patient was compelled to wear. There may have been some cures, but the annoyance to the wearer must have been great. The practice may have been abandoned, but, if so, it was revived again by Paré in the sixteenth century.

Classes of Heterotropia.

There are two classes of heterotropia—the one occurring at any period of life, and always due to paralysis or paresis of one or more of the ocular muscles, and practically always curable by medication; the other occurring in infancy or early childhood, and never caused by either paralysis or paresis. The former will be studied in Chapter XI., where the means of making a differential diagnosis will be set forth. It will be studied as paralytic heterotropia.

Comitant Heterotropia.—Of this condition there are the several varieties that have already been mentioned, each of which will be studied separately from the standpoint of both etiology and treatment. In lateral heterotropia, although the visual axes are not properly related—either crossing within the point of view, as in esotropia, or crossing beyond the point of view, often being parallel, or even divergent, as in exotropia—the two eyes, nevertheless, are made to move equally far directly to the right or left, or in any oblique direction—that is, the one visual axis accompanies the other in every movement, in any direction, the degree of variation from the normal always remaining the same. In vertical heterotropia one visual axis rises above the other, as in hypertropia, or one visual axis falls below the other, as in catatropia; but when the two eyes are rotated directly up or down, or in any oblique direction, the angle of deviation always remains the same. In comitant cyclotropia, it is reasonable to suppose that the vertical axes diverge or converge the same in all movements of the visual axes. No better word, therefore, could be chosen for defining these conditions than "comitant." The old term, "concomitant," is probably neither better nor worse than the shorter term adopted by Maddox, Jackson, and other authors.

The term "comitant" would not be needed except that

it makes it easy to distinguish true heterotropia from paralytic heterotropia. In the discussion of the latter in the next chapter, it will be shown that, in some one part of the field of rotation, the visual axes will be properly related, giving binocular single vision, whatever muscle may be paralyzed; while rotation in the opposite part of the field will be attended by a lagging behind of the visual axis of the eye to which the affected muscle belongs, which will always be shown by diplopia, and often may be detected by the observer. Diplopia, under ordinary conditions, does not manifest itself in comitant heterotropia, for the reason that the occurrence of the error early in life made it possible for the mind to suppress the images in the wrongly-directed eye that otherwise would have interfered with objects seen by the properly-directed eye. Equal deviation in all positions of the eyes and no diplopia means comitant heterotropia; unequal deviations—none at all in one direction, but greater or less in the opposite direction, with single vision in one part of the field and diplopia in the opposite part—mean paralytic heterotropia. In the former there is no disturbance of locomotion, while in the latter the patient becomes more or less dizzy. In the former, the secondary deviation is equal to the primary deviation; in the latter, the secondary deviation is always greater than the primary.

The etiology of comitant heterotropia can be studied to better advantage in the discussion of the individual varieties.

Comitant Esotropia.—This condition—known also as internal strabismus, internal squint, and cross-eyes—is the most common form of heterotropia. It always occurs in early life, usually at the age of two or three years. The conditions causing the error exist from birth, and only one of the several natural causes undergoes any change at any time after birth. In the greater number of cases it is the character of the nerve impulse to the ciliary muscles that causes over-stimulation of the third conjugate innervation center, which over-stimulation causes an actual deviation, when previously there was only a tendency toward deviation—a conversion of an esophoria into an esotropia. Why this change should not occur earlier than the second or third year is variously explained. Usually authors are agreed that children look at near objects but little until two years old, at which time they begin to take interest in toys and pictures, looking intently at them, at close range. Children who become esotropic are nearly always hyperopic, hence are forced to use their ciliary muscles in far vision, which means that, in near vision, an excessive nerve impulse must be generated and sent to these muscles. A correspondingly increased impulse

is sent to the interni, which are naturally too strong for the externi, and the eyes cross.

Maddox teaches in his work, "The Ocular Muscles," that the lenses increase in density even in infancy, and by the time the child is two or three years old a greater impulse is needed by the ciliary muscles to effect the necessary change in the convexity of the lenses. This increase of ciliary impulse is attended by a corresponding increase of the convergence impulse, which develops the esotropia. This would occur whether the child were hyperopic or emmetropic. An acceptance of either explanation throws the immediate blame for the crossing of the eyes on the ciliary muscles.

Whatever may be the reason for the short delay in the manifestation of esotropia, there must be a cause or causes that finally develop the condition. The following factors will be discussed in the order of their importance: Esophoria, hyperopia, hyperphoria of one eye and cataphoria of the other; a lower state of visual acuity in one eye than in the other, either from some congenital abnormality in the perceptive, transmitting, or receptive part of the apparatus, or some opacity or irregularity of the refractive media, either congenital or the result of disease, or because there is a greater error of refraction in one eye than in the other. Finally, the whole of the macula in one eye may be connected

with one side of the brain, while the whole of the macula in the other eye may be connected with the other side of the brain. A sixth complication, if not a cause, is a plus or minus cyclophoria.

Esophoria as a Cause.—It is safe to say that without esophoria there can be no esotropia; but ordinarily esophoria must be aided by one or more of the other causes in the production of esotropia. Esophoria, when high in degree, may eventuate in esotropia, and at the usual age or earlier, when there is no hyperopia, even when the refractive error is myopic. When esophoria alone is the cause of esotropia, the actual turning occurs when the externi, always too weak as compared with the interni, give up the task of so antagonizing the interni as to make binocular vision possible. At this time the mind selects one eye for use, and the other is allowed to turn into the position predetermined by the excessive power of its internus. If its plane of action coincides with the horizontal plane of the eye, the position assumed will be directly in toward the nose; if the plane of its action is elevated, its attachment being too high, the eye will turn up as well as in and will be torted in; but if its plane of rotation is depressed, its attachment being too low, the eye will be turned down as well as in, and will be torted out. At the time of the beginning of the in-turning, the mind, in the interest of single vision,

begins the work of suppressing the images on the retina of the in-turned eye. If the esotropia is not periodic or alternating, the work of mental suppression is soon accomplished, the patient becoming mind-blind in the crossed eye. When an esophoria alone is the cause of esotropia, the error probably shows itself earlier than usual. Spontaneous recovery, in such a case, will never occur. For a study of esophoria, the reader is referred to Chapter IV. of this book.

HYPEROPIA AS A CAUSE.—When hyperopia, or hyperopic astigmatism, is one of the causes of esotropia, it is not the quantity of the error, but the character of the required impulse for its correction, that enters as a factor. A greatly excessive impulse may be needed for the correction of a small error, while an impulse not so great gets a more ready response on the part of the ciliary muscles for the correction of a greater error. The excessive activity of the center for the ciliary muscles causes over-excitation of the third conjugate center, thus developing a pseudo-esophoria. This grafted on an intrinsic esophoria may readily convert it into an esotropia. The foundation for every permanent esotropia is intrinsic esophoria. An esotropia caused by hyperopia alone will be periodic, and never permanent. In such cases, suppression of images is impossible. In cases of esotropia, in which spontaneous recovery takes place, hyperopia has

been the chief cause. If the esotropia spontaneously cured has lasted very long, mental suppression has accomplished its work, and the eye once crossed remains low in visual acuity.

The position assumed by an esotropic eye when the two factors, esophoria and hyperopia, have acted together, is always determined by the character of attachment the internal rectus may have. The eye may be turned straight in, or in and up with inward torsioning, or in and down with outward torsioning.

The esophoria unassociated with hyperopia, in many cases, would not have caused esotropia; hence it appears reasonable to conclude that a correction of the hyperopia would result in a reconversion of the esotropia back into esophoria. This is just what is accomplished in a large per cent of the cases of esotropia that are brought early to the oculist. Thus cross-eyes are straightened without operation; but this does not mean that an operation may not be required later for the cure of the esophoria, for the relief of reflex troubles.

HYPERPHORIA AND CATAPHORIA AS CAUSES.—The plane of action of the superior and inferior recti is such that they not only turn the eyes, respectively, up and down, but they also turn them in. Imbalance of the superior and inferior recti, whether that imbalance is shown in a hyperphoria of one eye and a cataphoria of

the other, or in a double hyperphoria or in a double cataphoria, will become a factor in the production of esotropia only when there is an esophoria. When these two causes act together, the crossing will occur at the usual age (in the second or third year); but the esotropia will be complicated by a hypertropia or catatropia. If there is an eso-hypertropia and the superior rectus is the cause of the hypertropia, there will be a minus cyclotropia of that eye. If the fellow eye becomes eso-catatropic under cover and the catatropia is caused by the inferior rectus, there will be a plus cyclotropia of this eye. In double eso-hypertropia, the hypertropia being caused by the superior recti, there will be also a minus cyclotropia of each eye; and in double eso-catatropia, the catatropia being caused by the inferior recti, there will be also a plus cyclotropia. When, in eso-hypertropia, the hypertropia is effected by both the superior rectus and the inferior oblique, there will be no cyclotropia; when, in eso-catatropia, the catatropia is caused by both the inferior rectus and the superior oblique, there will be no cyclotropia.

There are cases of double eso-hypertropia, in which there is marked plus cyclotropia, easily observed without instrumental aid. The cause of the hypertropia in these cases is to be found in the inferior obliques, which muscles also cause the plus cyclotropia. In these cases the

esotropia is wholly due to the interni. That the turning up is not helped by the interni is shown by the existence of the plus cyclotropia; for, while a too high internus will turn the eye up, it will not tort it out. Thus it appears that a hyperphoria, caused by the inferior obliques, cannot be a direct factor in the causation of esotropia. If not a cause, it must be considered as a most important complication. The possible factors of esotropia and its complications can be found only by means of a most painstaking examination with the phorometer, cyclo-phorometer, and tropometer, or perimeter.

Low State of Visual Acuity as a Cause.—This condition, whatever may be its cause, can be only a secondary factor in the production of esotropia; for in these cases, as in all others, esophoria is the chief factor. If the low visual acuity is due to some congenital condition, or is caused by disease or injury in early infancy, the esophoria will be transformed into esotropia in early life. If both eyes have been good for any number of years, when disease or injury renders the vision of one eye bad, or even destroys vision altogether, this eye will become esotropic, if esophoria has previously existed; if there is no esophoria, there can be no esotropia, however low may become the vision of one eye. An eye that becomes blind will continue to move in harmony with its fellow, if previously there has been no form of hetero-

phoria. If there is known to be a certain kind of imbalance of the muscles when the vision in both eyes is good, should the vision of one eye be much reduced, or even lost, a positive prediction can be made as to the kind of heterotropia that will result: the turning will always be in the direction of the tendency. If there is perfect balance of all the ocular muscles, diminution, or loss, of vision of one eye will not interfere with the harmonious movements of the two eyes; a blind eye, under perfect muscle adjustment, will always appear to fix the object seen with the good eye.

Faulty Connection of the Maculas with the Brain as a Cause.—There are cases of esotropia in which it is impossible to fuse the two images of an object. Such cases were observed by Graefe, who defined the condition as "antipathy to binocular single vision." The cause of this antipathy, in all probability, is that the macula of one eye is connected with one side of the brain, while the macula of the fellow eye is connected with the other side of the brain. To fuse images on the two maculas their impressions must be carried to the same side of the brain, which cannot be accomplished unless the nerve fibers passing from the two maculas find their way into the same optic tract and thence go to the same cuneus. If the maculas fail to have a common connection with the brain, other retinal points that ought to

correspond cannot do so, and there must be diplopia in all parts of the field. The condition, if it exists, is congenital, and the only reason why there is not annoying diplopia must be due to the habit of mental suppression acquired in infancy. Esotropia due to such a cause must occur earlier in life than is usual, possibly within the first few weeks after birth.

Pathology points to the possibility of such a cause for esotropia. A disease involving the center of sight in one cuneus, or a disease involving all the nerve fibers as they pass from one cuneus in their course to the optic chiasm, whether in the tract or farther back, must cause hemianopsia, involving corresponding halves of the two retinas, the temporal half of one retina and the nasal half of the other. Many such cases have been observed. In some cases the line dividing the blind part from the seeing part of each retina has been vertical, passing down through the macula; in other cases, while these lines were vertical, they missed the maculas, passing a few degrees either to the right or to the left of both, the two maculas falling either in the blind or in the seeing parts, in either case showing that both were connected with the same side of the brain; in other cases the dividing lines have not been vertical, the obliquity being sometimes as much as ten degrees, but the same in the two eyes. The oblique lines have passed, in the reported

cases, either through the maculas or have fallen on corresponding sides. No case, so far as the author knows, has ever been reported showing that the blindness in the temporal half of one retina included the macula, while the blindness in the nasal half of the other retina did not include the macula, else no further argument would be necessary. That pathology has shown no cases of faulty connection of the maculas with the brain is probably due to the rarity of the condition—certainly as rare as is "antipathy to binocular single vision," for the one must be a synonym of the other. If the lines dividing the retinas into two halves pass, in some cases, down through the maculas, while in other cases both these lines pass either to the right or to the left of the maculas, it must be conceded as a possibility that the dividing line in one retina may pass to the right of the macula, while the dividing line in the other retina may pass to the left of the macula. In this case disease of one cuneus or of one tract would destroy the perceptive power of one macula, while the other macula would be uninvolved. There being no disease in such a case, the impress of an image on one macula would be conveyed to one side of the brain, while the impress of the image on the other macula would be sent to the other side of the brain, and there could be no fusion of the two. So far as the author can see, nothing

else can account for "antipathy to binocular single vision."

Every surgeon of much experience with esotropia has had cases that he could not cure, however skilled as an operator. Each attempt to correct the error in such a case makes the patient worse, for the reason that, under the old condition, the power of suppression of images in one eye had been acquired, while under the new condition, the images fall on new parts of the retina of the eye operated upon, and diplopia is at once made manifest. The more nearly the readjustment of the muscles brings the eyes straight—to exactly straighten them is impossible—the more annoying becomes the diplopia. If the patient is mature at the time the operation is done, his diplopia will always be annoying, for he can never reacquire the power of mental suppression. To have let such a patient alone would have been a mercy.

Fortunately, esotropia due to the cause under discussion is rare. That the mistake of operating on such cases may not be made, the operator should give most careful study to every case. When there is great amblyopia of the esotropic eye, one may feel fairly sure that the case is not of this character; for usually a case of this kind has fairly good vision in either eye when the other is excluded, for the esotropia is alternating. But all cases of alternating esotropia, with fairly good vi-

sion in each eye, do not belong to this hopeless class. In any case of esotropia the fusion test should be applied; but in alternating esotropia this test becomes absolutely essential. When the images can be fused, the case can be cured; if the images cannot be fused, a cure is impossible, and should never be attempted. The method of making the fusion test will be given farther on, and the peculiar play of images that cannot be fused will be shown.

The varieties of comitant esotropia have already been mentioned incidentally. They may be grouped here as follows: Periodic, alternating, and permanent. The same case, at different times, may present these different conditions. Periodic esotropia is always curable; while alternating esotropia may be curable, it is always open to the suspicion that there is "antipathy to binocular single vision." Permanent esotropia is usually attended by pronounced amblyopia in the deviating eye, and practically always depends on causes that can be relieved. Occasionally a case of permanent esotropia may belong to the incurable class, in which there is "antipathy to binocular single vision."

Comitant esotropia must be differentiated from apparent esotropia and from paretic esotropia. The cover test at once settles the question as to apparent esotropia, for, on covering and uncovering the eyes alternately,

there will be no resetting of either eye, both visual axes always pointing toward the test object. The cover test, in comitant esotropia, always shows a resetting of both eyes when covered and uncovered alternately. Under this test there are always present the primary and the secondary deviations—the one equal to the other. In paretic esotropia the secondary deviation is always greater than the primary deviation, for the reason that if the paretic muscle is the right externus, the fourth conjugate innervation center sends an excessive impulse to the right externus, because it is paretic, and to the left internus, causing the latter to manifest excessive power. On covering the paretic eye and uncovering the good eye, the fifth conjugate innervation center sends only an ordinary impulse to the left externus and the right internus, hence the slighter deviation of the eye to which belongs the paretic muscle.

The complications of esotropia are: hypertropia of one eye and catatropia of the other, double hypertropia, double catatropia, and cyclotropia. Hyperopia and hyperopic astigmatism may also be considered as complications. In the treatment of esotropia, it is essential that all these complications shall be either found or excluded.

The Fusion Test.—There is no test, in the investigation of a case of comitant esotropia, so important as

the fusion test. The ability to fuse images should be determined, regardless of the time it may take. If a patient could be made conscious of double vision at once, the ability to fuse could be quickly found. The test object should be a candle or a gas jet. Placing a red glass before the good eye, the natural light is often easily found by the deviating eye, and on the corresponding side. If the red glass before the good eye does not bring out the consciousness of the double candle, then a green or a blue glass may be held before the deviating eye, thus discoloring both images. As soon as the two discolored lights are seen, the glass before the deviating eye may be removed, when, with comparative ease, the natural light is seen by this eye, while the red light is seen by the fellow eye. If the two are not level, they should be made so by means of the proper prism, placed vertically. Now, by means of the rotary prism before the deviating eye, the yellow blaze should be made to approach the red one. If they are more than ten degrees apart, a supernumerary prism should be placed, with its base out, behind the rotary prism, when, starting again at zero, the index is again carried into the nasal quadrant; and as it revolves, the lights are brought nearer and nearer, until finally they merge into one. In the whole test, the fixing eye is the good eye, and the fixed object is the red light. The fusion is effected the moment the

yellow image is thrown, by prismatic action, on the macula Once fused, there should be no diplopia so long as the fusing prisms remain unchanged. Whenever fusion is found possible, the case is curable.

If there is antipathy to binocular single vision, the false (yellow) light can be made to approach the true (red) light, but cannot be made to fuse with it. The two will "kiss" and then recede, or the one will rise above or fall below the other and pass to the opposite side. Any number of repetitions of the effort to fuse, by means of the most careful use of the rotary prism, will result in failure. Such a case is incurable by any and every means; and, therefore, no attempt should be made. Operations certainly make these cases worse.

Comitant esotropia is a monocular trouble only in appearance. In reality it is binocular—a fact that should always be remembered when operations are about to be done for its relief. The binocular character of esotropia is shown by the cover test; for the moment the deviating eye is made to fix, because the good eye is covered, the latter turns in. After operations have been done on the deviating eye, it sometimes becomes easier to use this eye, at which time the fellow eye turns in, but not so much as the original eye had turned. This use of the eye that before deviated, favors the cure of the amblyopia, without detriment to the other eye.

Measurements of Esotropia.

There are several methods, some more accurate than others, but all of them of some value. The phorometer test is the only one that is perfectly correct; and, unfortunately, it is the hardest one to accomplish, for the reason that it is so difficult to develop consciousness of diplopia. If diplopia could always be made manifest, the other methods of measurement would soon be discarded. The angle *gamma* does not interfere with the phorometer test, but it does militate against all other tests. This angle is formed at the crossing of the visual axis and the line commonly called the "optic axis," at the center of the retinal curve, which is the center of rotation of the eye. For a better understanding of the angle *gamma* the lines whose intersection forms it should be studied. The visual axis begins always at the *fovea centralis*, and must always pass through the center of motion, which is the center of retinal curvature, and thence it must pass through the cornea, but at no definite point; it may be its center, but more often the point through which the visual axis passes is away from the corneal center. The visual axis is the antero-posterior axis of rotation. It is strange how the line of fixation should ever have been conceived as other than the visual axis; and yet the cut in Swanzy's book, edition of 1900, page 25, shows the visual axis passing from the supposed

macula through the nodal point out to an object in space. The same cut shows the line of fixation extended from the object in space to the center of rotation, stopping there. Had he extended it back to the retina, he would have missed the supposed macula, as shown in his cut; but it would have passed to the real macula, for the line of fixation can be none other than the straight line that, passing through the center of rotation, connects the object and its image on the macula. The so-called "optic axis" is the line that must begin at the center of the cornea and must pass through the center of rotation and may reach the macula, but more often misses it. This line, unless it coincides with the line of fixation, cannot be an axis of rotation, for the reason that it cannot pass through the equatorial plane at right angles; for the equatorial plane must be at right angles to the line of fixation—the visual axis. The point always common to these two axes, or lines, is the center of rotation of the eye, and the angle formed by their intersection is the angle *gamma*. The average size of this angle is about five degrees, though in an ideal eye it is nothing. When this angle is to the nasal side of the visual axis, the eye that is straight would appear to be esotropic; if to the temporal side, the eye would appear to be exotropic. The angle is more often temporal than nasal; hence an esotropia would appear less than it really is, while an exotropia

would be exaggerated by it. This angle can always be measured by the perimeter, and, when known, can be taken from or added to, as the case may be, the esotropia that has been previously measured in any other way than by the phorometer.

MEASUREMENT BY THE PHOROMETER.—A red glass should be placed before the good eye. Before the deviating eye should be placed the rotary prism in the position for testing for lateral heterophoria, with the displacing prism of six degrees, base up, in the cell toward the eye. The red and the yellow blazes of the candle or gas jet having been found, the latter will appear more or less removed from the vertical line passing down through the red light and in the direction corresponding to the deviating eye. The fifteen-degree supernumerary prism should be placed, base out, in the front cell, which will carry the yellow light just that far toward the vertical line passing through the red light. Revolving the rotary prism in the nasal arc, the yellow light is carried still nearer the vertical line, which it may be made to reach at some point between zero and ten degrees; but if this falls short, the rotary prism should be revolved back to zero, and a stronger supernumerary prism (twenty degrees, twenty-five degrees, or thirty degrees) should be placed in the anterior cell. Now the rotary prism should be turned again in the nasal arc and then stopped at that

point where the patient declares the yellow light directly under the red one. If the twenty-five-degree prism is in the front cell and the rotary prism stands at seven degrees, the prism-degree measurement of the esotropia is thirty-two degrees, one-half of which would give the degrees of arc—viz., sixteen degrees. As already stated, the angle *gamma* does not have to be considered in connection with the phorometer measurement. It would be very difficult to take the measurement of esotropia with the prisms of the refraction case held by the hands of the operator. Though this would be tiresome and tedious, it, nevertheless, would be accurate.

Measurement by the Perimeter.—Have the head placed as if the purpose were to take the field of the non-deviating eye, which should be made to fix the point in the center of the semicircle. A candle or small electric light should be moved along that arc toward which the deviating eye points, and it should be stopped the moment that the image reflected from the center of the cornea, the light, and the eye of the observer are in line. The number on the perimeter arm, at the point where the light was stopped, gives the measurement of the deviation in arc degrees. If the esotropia thus measured should appear to be twenty-five degrees, it will be more if the angle *gamma* is temporal, or less if this angle is nasal. The next step is to determine the pres-

ence or absence of the angle *gamma*, and, if present, its size. To do this, the good eye must be covered while the patient fixes, with the esotropic eye, the point in the center of the perimeter arc. When the candle is held immediately behind this point, if the image is reflected from the center of the cornea so that the image, the light, and the eye of the observer are in line, there is no angle *gamma*, and, therefore, nothing is to be taken from nor added to the measurement of the esotropia; but if the light must be moved in the temporal arc for the image, the light, and the eye of the observer to be in line, there is an angle *gamma*, the size of which is shown by the number at the point on the perimeter arm at which the light was stopped when the image appeared reflected from the center of the corneal surface. The angle thus formed being temporal, it should be added to the measurement of the apparent esotropia, in order to show the quantity of the real deviation; but if, in finding the angle *gamma*, the light has been moved into the nasal arc, the angle would be nasal, and should be subtracted from the measurement of the apparent esotropia, in order to show the quantity of the actual deviation. If the perimeter is carefully used in the manner set forth, the results must be correct. It is applicable to all cases of esotropia in which the deviating eye can be made to fix when the good eye is covered; while the

phorometer method can be used only in those cases in which, by means of a red glass before the good eye, consciousness of diplopia can be awakened.

When the squinting eye cannot see, therefore cannot fix, the angle *gamma* cannot be measured, and for this reason it cannot be taken from nor added to the perimeter measurement of the esotropia.

THE TAPE MEASUREMENT.—Priestly Smith's method of measuring esotropia is easy and fairly accurate. By this method the angle *gamma* is not considered. To make this test, one must have an ophthalmoscope; two tape lines, each one meter long; and a candle, a lamp, or a gas jet. The tape lines, at one end, should be fastened to a ring large enough to allow the handle of the ophthalmoscope to pass through it, while the other two ends should be free, and on one tape should be a scale indicating arc degrees. With the light above and behind the patient, the operator seats himself one meter in front of him. He gives to the patient the free end of the unmarked meter tape, and tells him to place it immediately beneath his good eye; and then, with the ophthalmoscope in front of his own eye which corresponds with the patient's non-deviating eye—that is, his right eye, if it is the patient's left eye that turns in—he withdraws from the patient as far as the tape will allow whose ring end is fastened to the ophthalmoscope, or to

the thumb of the hand holding the ophthalmoscope. He directs the patient to fix the hole in the mirror while he reflects the light into the fixing eye. If there is no angle *gamma*, the operator sees the image of the blaze reflected from the center of this cornea; but on reflecting the light into the deviating eye, while the good eye still fixes the hole in the mirror, the image of the blaze will be seen toward the temporal margin of this cornea, the distance from the center corresponding to the amount of the esotropia. The operator now takes the marked meter tape in his free hand (he holds the mirror before his right eye with his left hand, and *vice versa*) close to its attachment to the ring, and, slowly extending it at right angles to the other tape, he directs the patient to look at his moving thumb with his good eye. Throughout this step in the test, the light from the mirror is kept on the cornea of the deviating eye, and the operator watches the reflected image as it approaches the center of the cornea. The moment the image is seen at the center of the cornea the operator stops the movement of his hand, and immediately reads on the scale the number of degrees the good eye had to move toward the nose in order that the deviating eye might become straight. Since the two eyes moved comitantly, the reading on the scale is the measurement of the esotropia. This method is not as accurate as either the phorometer or the perim-

eter methods, for the reason that one cannot be certain that the marked tape is at right angles to the unmarked tape.

LINEAR MEASUREMENT.—Lawrence's strabismometer, which is the best means for taking the linear measurement of squint, is rapid, but not accurate, in its work The lid piece is concave on one side so as to rest evenly against the lower lid; on the convex side it is graduated in millimeters in both directions from the central point, which is marked zero. In making the test, the operator covers the good eye, thus forcing the patient to fix some distant object, immediately in front, with the deviating eye. The instrument is now placed in contact with the lower lid of the now-fixing eye, so that the point marked zero may be directly in line with the center of the pupil. On uncovering the good eye, it at once fixes the test object, while the deviating eye turns toward the nose. The extent of the turning in millimeters is shown by that mark on the scale that falls immediately beneath the center of the pupil.

HIRSCHBERG'S METHOD.—By this method accuracy cannot be attained. The test object is a candle held twelve inches from the patient, and immediately before him on a level with his eyes. With both eyes uncovered he is directed to look at the candle. The image of the candle is reflected from the corneal center of the fixing

eye, but from the temporal side of the cornea of the esotropic eye Hirschberg estimates that the deviation is ten degrees or less, if the reflected image is nearer the center than the margin of the pupillary area; from twelve degrees to fifteen degrees, if the image is at the margin of the pupil; twenty-five degrees, if the image is halfway between the center of the cornea and its margin; from forty-five degrees to fifty degrees, if the image is at the corneal margin. Esotropic cases were divided by Hirschberg into these several groups that he might determine the kind of operations to be done in any individual case. Since complete tenotomies ought never to be performed on esotropes, the Hirschberg method of testing is of no use.

Symptoms of Comitant Esotropia.

There is no nervous tension of the externus of the esotropic eye, for the position assumed by this eye is that of equilibrium of all the recti and the oblique muscles. The tension of the externus of the fixing eye may be lessened, if not relieved, by a turning of the face toward the corresponding side, so as to let the visual axis cross the extended median plane of the head between the eye and the object of fixation. Headache or other symptoms, in these cases, usually attributed to eye-strain, depend largely on the abnormal tension of the externus of the fixing eye, though this is sometimes relieved by

an acquired side-pose of the head. But in some of these cases it may depend on the nervous tension of the ciliary muscle in its effort to correct the hyperopia or hyperopic astigmatism of the fixing eye, together with the associated tension of the ciliary muscle of the non-fixing eye; or it may result from the effort of the obliques to parallel the vertical axis of the fixing eye with the median plane of the head.

AMBLYOPIA.—The one subjective symptom common to most cases of permanent esotropia, and that may exist unnoticed for many years, is amblyopia of the non-fixing eye. While in some cases this may be congenital, in most cases it is acquired. The blindness is in the mind, and not in the eye. Nature has provided only two methods by either one of which a person may be freed from the annoyance of seeing everything double: First, the proper regulation of the visual axes by the recti muscles, so that they may always be in the same plane and converged at the point of view, and the paralleling of the vertical axes of the eyes with the median plane of the head, thus making binocular single vision possible; second, in the absence of any one or all three of the conditions essential to binocular single vision, then mental suppression of the images in one eye. The habit of mental suppression cannot be established, except in infancy and early childhood. Once this habit is estab-

lished, it is hard to break at any period of life; but the task can be more easily accomplished early in life than in later years. In all cases it is probable that the amblyopic eye would become useful, if accident or disease should destroy the fellow eye. W. B. Johnson, of Paterson, N. J., has observed and reported two such cases. His report has done much to prove that *amblyopia ex anopsia* is not a myth. Faithful exercise of the little visual power of the amblyopic eye, by covering the good eye, will greatly improve its vision, especially in young persons. Without this special exercise it has often been noticed that vision improved in the formerly non-fixing eye after the muscles had been readjusted so as to properly regulate the visual axes and the vertical axes. There is now but little room for doubting that the amblyopia of esotropia is mental, and not ocular.

The chief objective symptom is disfigurement. However beautiful a young lady may be otherwise, if her eyes are crossed that beauty is marred; and if she is otherwise unprepossessing, crossed eyes could but render her more so. A young man afflicted with esotropia cannot be so handsome as he would be if his eyes were straight. A girl or boy, a woman or man with esotropia is at a decided disadvantage from a cosmetic point of view; and if there was no other reason for operating, this one would be sufficient.

An objective symptom that should never be neglected in the study of any case of esotropia is the turning in of the good eye when under the cover, at which time the fellow eye must become the fixing eye. The secondary esotropia should be equal to the primary; but if the secondary esotropia is greater than the primary, it points to paretic, and not to comitant, esotropia.

COMPLICATIONS OF ESOTROPIA.—These are errors of refraction; hypertropia, single or double; catatropia, single or double; hypertropia of one eye and catatropia of the other; and cyclotropia, either plus or minus. Hypertropia, catatropia, and cyclotropia will be studied farther on in this chapter. Here it may be said that these errors, if unassociated with esotropia, would often be phorias, and not tropias. Nevertheless, before operating for esotropia, it is important to know if these errors exist; it is also important, before operating for esotropia, to study well the refraction of the two eyes, and to correct those errors (hyperopia and hyperopic astigmatism) that are not only complications of esotropia, but act as causes also. Another condition which complicates esotropia is amblyopia, which is also a result of esotropia.

TREATMENT OF ESOTROPIA.

Hyperopia and hyperopic astigmatism, often a complication of esotropia, are just as often causative of this.

condition. A very few cases of esotropia have, for their chief causes, these errors of refraction. It is only a case of this kind that eventually recovers spontaneously; but spontaneous recoveries are rare. Nor should these cases be allowed to wait for such a recovery, which would be years in coming; but they should be cured at the earliest possible moment. The only treatment needed for such cases is the full correction of the hyperopic error, and at the earliest time possible. Such a patient, if only two years old, will wear the correcting lenses kindly, because of the relief experienced. If the spectacles are not given to the little fellow promptly after his morning toilet, he will call for them. It is often interesting to experiment with such a case by having him look at some distant object one moment through the lenses, when the eyes will be straight, and then a moment without the lenses, when the eyes will cross. The repeated raising and lowering of the lenses will show alternate crossing and straightness. One who has seen these changes cannot reasonably doubt the effectiveness of convex lenses in the treatment of esotropia.

There are two reasons for the early adjustment of convex lenses in the treatment of esotropia. One is that it is in the earliest years of life that the power of mental suppression of images in the deviating eye is acquired. To prevent this amblyopia is to cure the esotropia; or,

if the habit of suppression has already been formed, the early correction of the esotropia gives the patient a chance to recover the lost vision with greater ease than would be possible in later years. The other reason for the early correction of the hyperopic error that has caused the esotropia is the relief the lenses give to the brain-center that supplies power to the ciliary muscles. With the convex lenses on, this brain-center is no longer over-stimulated, and consequently the third conjugate center is no longer over-excited. The extra nerve force that must be expended by these centers, if the hyperopic error remains uncorrected, must be at the expense of nerve force needed by other centers.

Every little child whose eyes are crossed should be given the chance of a cure by means of spectacles. If the hyperopic error is the whole cause of the esotropia, the lenses will certainly effect a speedy cure; if the hyperopia is only one factor, while esophoria is the other factor, in the production of esotropia, the early correction of the focal error will often make it impossible for the esophoria to continue to transform itself into esotropia. The eyes can be straightened, in some of these cases, by means of convex lenses, but the esophoria will remain. Later, because of nervous symptoms, the esophoria may demand treatment, either surgical or non-surgical. To do any kind of surgery for the cure of an esotropia that

has for its sole cause a hyperopic error must result in harm. In early life no case of esotropia that is hyperopic should be subjected to operation until it becomes evident that convex lenses cannot straighten the eyes. It is doubtful if the almost universal practice of keeping such eyes under the influence of atropine is helpful, but certainly both eyes should be under the influence of either atropine or homatropine at the time the measurements are taken, and the full error thus found should be corrected. Worth is correct in his advocacy of atropine in the good eye only after the convex lenses have been given, and the reason for this is not far away: it allows the child to use the better eye for distance, but forces him to use the deviating eye for near objects—a very good way for curing the amblyopia. For the same reason atropine could be used in the good eye when there is any other form of heterotropia.

If in a month or two convex lenses do not cause the eyes to swing straight, surgery should be resorted to, however young may be the patient. By "surgery" is meant the right kind of surgery—partial tenotomies of the interni, with or without shortenings of the externi. A complete tenotomy in the case of a child should never be done, and advancements should be avoided. Very slight operations, if done in early life, will accomplish as much as more extensive operations done in later years;

but an esotrope never grows sufficiently old to justify complete tenotomies.

If the refraction of the eyes is myopic, this error cannot have been a factor in the production of the esotropia; hence the correcting lenses cannot aid in the cure. Surgery alone can bring these eyes straight. Such a case of esotropia can never recover spontaneously. An esotrope who is emmetropic can be cured only by surgery. Atropine used in the good eye will help after surgery has been resorted to.

Esotropic patients who have been allowed to go for years without treatment, whatever may have been the cause or causes, become more or less amblyopic in the deviating eye. In many of these cases the correction of the hyperopia, if it had been given early, would have speedily straightened the eyes; but if this correction is withheld until the suppression habit has become established, the cure, if it can ever be effected by the convex lenses, is much more tedious. Nevertheless, a fair trial of the lenses should be given, a great aid to which will be the forced use of the deviating—amblyopic—eye, for a short while, several times a day. This is done by placing a flap before the good eye, thus compelling the mind to receive the impression of the images on the retina of the bad eye. At such time, and at all times, the correcting lenses should be worn. At first only large

objects in the distance should be observed; later, pictures or large print should be looked at. If the patient is old enough, he will observe the improved state of his vision from week to week, and will thus be encouraged to continue; if the patient is a child, the exercise should be enforced, for the little one cannot appreciate the results. This practice at first may be continued only a few minutes—from ten to thirty; later, it should be prolonged for an hour or more; and, in either case, it should be repeated two or more times daily. The training of the mind to use the amblyopic eye is the best means for the beginning of the development of the fusion power. Whether a child or a grown person, the use of atropine in the good eye will help to train the mind to use the bad eye.

This training of the mind to use the amblyopic eye is necessary even in those cases that must be subjected to operations, else binocular single vision may not be obtained. The chief object in view in the treatment of esotropia, whether by lenses or by operations, or by both, is the establishment of binocular single vision. There should be fewer failures in this direction in the future than in the past. The forced use of the amblyopic eye will make success more certain.

After a few months of training, as set forth above, the stereoscope can be brought into use. At first the

two pictures used should be unlike, but of such a nature as to be easily combined. The best example is the picture of a bird before one eye and the picture of a cage before the other. The bird, at first outside the cage, will be observed by the child to approach and enter it, finally resting on the perch. Other pictures that can be associated should be provided. Later, cards may be used, on one end of which is drawn one part of an object; on the other end, the remaining part of the object. If the complete object is seen, the retinal images have been fused. Later, the pictures ordinarily used in the stereoscope may be given. To be certain that these pictures have been fused, it becomes necessary to make some change in each at different parts; for example, cut off the upper left-hand corner of one picture and the lower right-hand corner of the other. If an unmutilated picture is seen, the two retinal images have been fused. Many other changes, such as placing different kinds of marks on the pictures, would readily suggest themselves. When the esotropia is of high degree, training by means of the ordinary stereoscope is impossible.

The best means for training the fusion power is, probably, the Worth reflecting stereoscope, or amblyoscope, shown in Fig. 52. This instrument can be used in any and all cases of esotropia; but before undertaking the training of the fusion faculty by this means, the ambly-

opia of the deviating eye should be treated in the manner already set forth. As shown in the cut, the Worth instrument consists of two symmetrical halves; each half is made by uniting two tubes, a long and a short one, at an angle of one hundred and twenty degrees, and the two halves are joined by the hinge shown at A. These

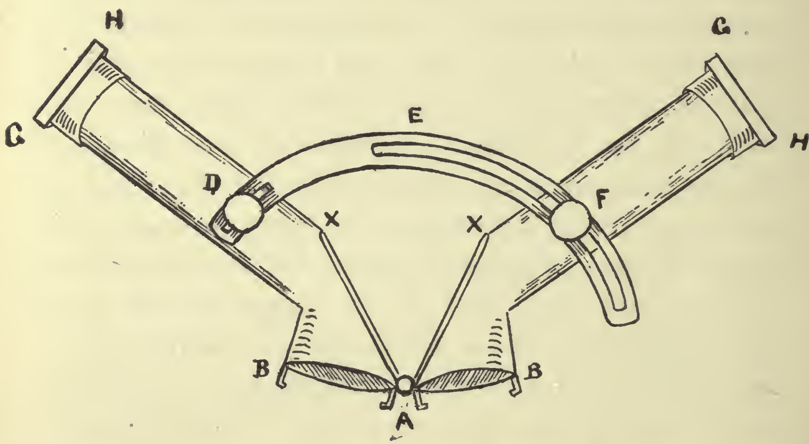

Fig. 52.

halves are further connected by the brass arc D-E-F, in which are two slots, and by means of which the distal ends of the tubes may be made to vary the distance between them. At D and F are binding screws for "fixing" the proper relationship of the tubes, when it has been attained, for any given pair of esotropic eyes. By

placing the binding screws at the inner ends of their respective slots the instrument is in adjustment for sixty degrees of esotropia, and by moving these screws to the outer ends of their respective slots the instrument will be in adjustment for thirty degrees of exotropia.

At G-H of each tube there is an arrangement for the insertion of translucent picture slides. At A-X of each tube there is an oval mirror. At the ocular ends A-B there are lenses of a certain power, which may be supplemented by other lenses that may be needed by any individual case, for making sharp the outline of the images reflected from the mirrors.

In using this instrument for training the fusion faculty, images that differ, and yet can be associated, should be placed in the distal ends of the tubes. The best example is the picture of a cage for one tube, and that of a bird for the other. The tubes must be related corresponding to the degree of deviation of the esotropic eye, so that the reflected image of the one picture may fall on one macula, while that of the other falls on the other macula. At first the patient may see only the cage, and not the bird, or *vice versa*. By increasing, relatively the intensity of the light entering the tube that is before the squinting eye, the bird is finally seen in the cage. Any two pictures that can be associated may be used, but none can be better than those of the bird and the

cage. Later, one may place in the tubes pictures that represent different parts of an object, the fusion of the two making the thing represented in parts appear as a whole. A very great variety of such pictures should be on hand, so as to make the exercise interesting to the little patient.

These exercises should not be undertaken until treatment has relieved, to a considerable extent, the amblyopia of the deviating eye. It would be well if the fusion faculty could be trained before operating, if circumstances will allow, and certainly before the final operations are done, if the best results are to be expected.

Bar-Reading.—Perhaps one of the best means for perfecting the fusion faculty is bar-reading. A strip of card-board, half an inch wide—or even a pencil, though this is hardly wide enough—should be held between the eyes and the printed page, about four inches from the latter. This will obscure some of the words for each eye, and will thus interfere with the reading, unless both eyes are being used. The words obscured for one eye are seen by the other, in binocular vision; therefore the bar does not hinder the reading; and, since this is so, the bar-reading exercise may be continued for hours at a time. There can be no question as to its value.

Treatment of the amblyopia is by excluding the good eye; by the adjustment of lenses that correct hyperopic

errors; by the use of atropine in the good eye, forcing the near use of the other; by the training of the fusion faculty with the simple stereoscope or the reflecting stereoscope, and, later, by bar-reading—these are non-operative means that should be applied to all cases of esotropia, even to those that must be subjected to operations.

Operative Treatment of Esotropia.

If all cases of esotropia could be treated at the earliest possible time—that is, when the condition first shows itself—probably not more than twenty-five per cent of them could be cured by non-operative means. Of this twenty-five per cent, a fair proportion would require, later in life, operations for the relief of the esophoria, which had been one of the causes, probably the chief cause, of the esotropia. A cure of esotropia, in the strictest sense, would mean that every causative factor has been removed. Convex lenses, given for the correction of hyperopic errors, remove only one factor; but in doing this much, they sometimes render inoperative the esophoric factor. However, the latter can be removed only by exercise or by operations.

It cannot be emphasized too strongly that complete tenotomies are not indicated in esotropia, even though the error should be high in degree; and if complete tenotomies should not be done, it goes without the saying

that the "check ligaments," so-called, should never be severed. It must be granted that some cases on whom complete tenotomies have been done have resulted in a cure of the esotropia, but it must be conceded also that a greater number have not been cured. One does not have to theorize as to the possibility of an esotropia's being converted into an exotropia by complete tenotomies of the interni, for this unfortunate result has been observed in a multitude of cases. In every complete tenotomy the control that comes from anchorage is lost. Uncut fibers of the tendon constitute the best anchorage; but if by accident all the fibers of a tendon should be cut, the divided tendon should be anchored to the globe by means of a stitch. Otherwise, the danger is great that the muscle may retract too far, and thus become a crippled muscle.

The only complete tenotomy that can be said to be at all safe is that advised by Panas. In this operation the hook is passed beneath the tendon (of the internus in esotropia), and by it the eye is rotated outward until the cornea is almost hidden behind the external canthus. This done, the force is relaxed and the tendon is completely divided. The element of safety lies in the fact that the over-stretched muscle has been rendered paretic, and, therefore, does not retract so far as it otherwise would do. The cut tendon becomes adherent to the globe be-

fore the muscle recovers from its paresis; hence its new attachment is as favorable for normal action of the muscle as it is possible for it to be after a complete tenotomy. The element of safety in the Panas operation is not sufficient to justify its adoption, in the face of the fact that there are safer operative means for the treatment of esotropia.

If advancements are done in connection with complete tenotomies, the latter become even more hazardous.

Landolt's method of treating esotropia by advancements of the externi alone is much to be preferred to complete tenotomies of the interni; for it is not attended by the danger of converting an esotropia into an exotropia, and it offers a better chance for the giving of binocular single vision in all parts of the field.

As in all other matters, so in operating for esotropia, extremes should be avoided. "The golden mean" is not an inapt expression. One extreme in the treatment of esotropia is complete tenotomies of the interni and the cutting of the check ligaments, without shortenings or advancements of the externi; the other extreme is advancements of the externi, without interfering in any way with the interni.

By the one method the strong muscles are made weak by setting them back (and, as already shown, the danger lies in the probability that they will be set back too far);

by the other method the weak muscles are made strong by bringing their attachments farther forward, with but little danger of bringing them too far. If enough could be accomplished by the advancements, in all cases, it would be almost the ideal operation.

The ideal operation for the cure of esotropia and its complications consists of advancements of both externi, or, if in young children, shortenings of both externi, to make them stronger, and partial tenotomies of both interni to make them weaker. The object in view is to bring the strength of the externi up to the normal both as to abduction and abversion, and to reduce the strength of the interni only to the normal both as to adduction and adversion. There is practically no danger of overreaching the limit in either of the two directions.

There are a few cases of esotropia, as will be shown farther on, in which it would not be correct to do anything primarily but advance the externi and depress their planes of rotation.

The two effects that can be accomplished by advancements are an increase of tension and a change of the plane of rotation. The former must always be accomplished, while the latter should be accomplished in some cases, but avoided in others. The two effects that can be accomplished by partial tenotomies are diminution of tension and a change of the plane of rotation. The

former must always be attained, while the latter must be accomplished in some cases, but avoided in others.

Before operating on any case of esotropia it must be decided whether the tension alone shall be altered, or whether, in connection with altering the tension, the plane of rotation shall be changed. To alter only the tension of the muscles, when their planes also should be changed, would be to fail to cure the case. In all cases in which the deviating eye is not totally blind it may be known beforehand just what kind of an operation should be done. If the deviating eye is totally blind, there can be no indication for a change of plane, and all that should be done for such a case would be to alter the tension.

The operative treatment of uncomplicated esotropia should be applied primarily to the deviating eye, with the view of leaving some of the error to be corrected by means of operations on the other eye. The externus of the deviating eye should be well advanced, straight-forward, so as to increase its tension without changing its plane of rotation, and at the same time a central partial tenotomy of the opposing internus should be done, the operator always being careful to leave uncut a sufficient number of fibers above and below to act as stay-cords. By this partial tenotomy the tension is reduced, but the plane is not changed. These two operations, done at the

same time, will usually enable the patient to fix with this eye, the other eye now becoming slightly crossed.

After an interval of two or more weeks a central partial tenotomy of the internus of the good eye should be done, with the view of lessening its tension without changing its plane. If it appears that the effect of this partial tenotomy is not enough, the externus of this eye should be shortened, straight-forward, at once; or, if a still greater effect is needed, this muscle should be advanced straight-forward. In either case the tension of the muscle would be increased, but its plane would not be changed. At the time the partial tenotomy is done, if there is doubt as to whether enough has been accomplished, nothing more should be done at that time. Later, if found necessary, the externus should be shortened.

In all uncomplicated cases of esotropia that cannot be cured or greatly helped by non-operative means, three operations—advancement of the externus, a partial tenotomy of the internus of the deviating eye, and (a little later) a partial tenotomy of the internus of the good eye—should be done; and a fourth operation—shortening or advancement of the externus of the good eye—may be demanded. If these operations are carefully done, the result should be a restoration of the power of binocular single vision.

If esotropia is complicated by a hypertropia of one eye and catatropia of the other and there is no cyclotropia, the operations for the cure of the esotropia should be done as if there were no complication—that is, by altering the tension of the lateral recti in such a way as not to make the slightest change in their planes of rotation. Later, or even simultaneously, the vertical error should be treated as will be set forth in connection with the study of the vertical deviations.

If esotropia is complicated by cyclotropia, the operations done for altering tension should be so done as to change the planes of rotation also. In esotropia with plus cyclotropia, but no hypertropia, the partial tenotomies of both interni should be marginal, including all of the lower and central fibers, and equal in extent, leaving uncut the upper fibers, thus altering tension and elevating the planes of rotation; and the shortenings or advancements, equal in extent, of both externi should be done so as to give them a lower attachment, unless it is shown by tests that the marginal tenotomies of the interni, which should always be done first, have fully corrected the plus cyclotropia. If the plus cyclotropia has been cured by the marginal tenotomies of the interni, the remaining part of the esotropia should be treated by straight-forward advancements or shortenings of the externi.

If esotropia is complicated by plus cyclotropia of both eyes and right hypertropia and left catatropia, the following plan of operating should be adopted: First, an advancement of the externus of the right eye so as to lower its plane of rotation. This would counteract, in part, the esotropia, the cyclotropia, and the right hypertropia; for the muscle, by means of its new attachment, would pull the eye toward the temple, draw it down, and tort it in. The second operation should be done on the internus of the left eye, and it should be a partial tenotomy, including all the lower and central fibers and leaving uncut only the fibers at its upper margin. By a reduction of the tension of this internus, the externus will draw this eye toward the temple, while the upper uncut fibers of the internus will pull the eye up and tort it in. Thus the esotropia will be further corrected, and the plus cyclotropia and the catatropia will be wholly, or in greater part, corrected. Any remaining esotropia must be counteracted by a central partial tenotomy of the right internus, and, if necessary, a straight-forward advancement of the left externus, for the reason that if by the first two operations the vertical heterotropia and the plus cyclotropia have been cured, the remaining esotropia would be uncomplicated and should be so treated, and for the further reason that should there still remain some of both complications after the first two opera-

tions, elevation of the plane of the right internus would increase the hypertropia while lessening the plus cyclotropia, and lowering the plane of the left externus would increase the catatropia, while lessening the plus cyclotropia. In such a case, therefore, the planes of rotation of the right internus and the left externus should not be changed, although it may be necessary to alter their tension. Any vertical heterotropia and plus cyclotropia remaining after the first two operations, should be corrected by a partial tenotomy of the superior rectus of the right eye, including all of its nasal fibers and as many of its central fibers as might be necessary. Should there still remain some of the left catatropia and plus cyclotropia, a partial tenotomy of the left inferior rectus should be done, including all the temporal fibers and as few as possible of the central fibers. The six operations performed in the order named, and done with proper care, should cure the worst case of this kind. The only remaining operations that should be done in such a case are: advancement of the nasal margin of the right inferior rectus and advancement of the temporal margin of the left superior rectus, the indication for which would be some remaining plus cyclotropia with right hypertropia and left catatropia. The first four operations usually accomplish everything that could be desired. To ignore the vertical heterotropia when com-

plicated by plus cyclotropia, or to ignore the plus cyclotropia when it is the only complication, in operating for esotropia, is to fail to cure the patient.

By far the most troublesome cases of esotropia—the incurable cases, under the old methods of operating—are those complicated by plus cyclotropia and double hypertropia. The primary deviation is in and up, and the eye is torted out; likewise, the secondary deviation is in and up, and the eye is torted out. In these cases the double hypertropia and the plus cyclotropia are both caused by over-action of the inferior obliques, while the whole of the esotropia is caused by over-action of the two interni, a large part of this over-action of the interni being in the nature of spasm. In some of these cases a division of the two inferior obliques will cure the double hypertropia, the plus cyclotropia, and the esotropia; and this was doubtless the operation done by the quack, Taylor, referred to in the first part of this chapter. The author has done this operation once, recently, and with gratifying results. These cases always carry their heads high, but they should be carefully studied otherwise than as to the pose of the head. In the more aggravated cases of this character, cutting across the inferior obliques by means of a Graefe knife, being careful not to injure the infraorbital vessels and nerves, is probably the best method of procedure. If

the inferior obliques are not to be cut in these cases, the first two operations should be done on the superior recti, at the same time, and should consist of a division of all the nasal and central fibers of each, leaving uncut only the temporal margins. These operations would lower the two eyes, and the uncut temporal fibers would tort both eyes in. In some of these cases these two operations go far toward curing, not only the double hypertropia and the plus cyclotropia, but also the esotropia. The next two operations, to be done at the same time or with a short interval between, are advancements of both externi. These operations should be done to increase the tension of these muscles, so as to counteract the esotropia, and lower their new attachments, so as to still further correct the double hypertropia and the plus cyclotropia. Usually nothing else will have to be done. Should there remain, after these four operations, some of the double hypertropia and plus cyclotropia, the nasal margins of both inferior recti should be advanced. Any remaining esotropia should be corrected by a central partial tenotomy of one or both interni, in such a way as not to change the plane of rotation; for to elevate the plane would be to increase any uncorrected hypertropia, while lessening any uncorrected plus cyclotropia.

Since minus cyclotropia, as a complication of esotropia, is so very rare, it is only necessary to say that, in

operating on the interni, their planes should be depressed; and in operating on the externi, their planes should be elevated, this being the very reverse of what should be done when there is plus cyclotropia.

If a patient should be unwilling to undergo all the operations that might be necessary for correcting his comitant esotropia, he may have the reflex nervous symptoms relieved by submitting to one operation—namely, a partial tenotomy of the internus of the fixing eye. This would relieve the nervous tension of the externus of this eye, without risk of interfering with the comitant movements of the two eyes, but it would not correct the esotropia.

Exotropia.

This condition, the opposite of esotropia, shows itself in such a deviation of one eye that its visual axis, instead of intersecting the visual axis of the fixing eye at the point of view, deviates from it. It is generally taught that myopia is one of the factors in its production. As taught in a previous chapter, pseudo-exophoria manifests itself only in the near; so it would appear that myopia, on which pseudo-exophoria depends, could have nothing to do directly in the causation of an exotropia that shows itself when the point of view is in the distance. Myopia does cause exotropia to be greater in the near than in the far. The true cause of exotropia is intrinsic ex-

ophoria. In a myope the exotropia first shows itself in the near, when the pseudo-exophoria is grafted on the intrinsic exophoria, the two together producing the exotropia. Beginning in the near, the exotropia will show itself later in the distance also, for the reason that the mind, learning to disregard, in near work, the images on the retina of the deviating eye, becomes able to suppress the images of distant objects, and this suppression leads to the conversion of the exophoria into exotropia. In this way myopia does contribute to the production of exotropia. An early cure of the pseudo-exophoria, by a full correction of the myopia, prevents an exotropia in the near that does not exist in distant vision, and the intrinsic exophoria may remain unchanged through life. If myopia were as common as hyperopia, exotropia would be found as often as esotropia; for intrinsic exophoria exists in fully as many cases as does intrinsic esophoria.

Exotropia may depend only on the excessive strength of the externi as contrasted with the interni. This difference in relative strength may be due to hyper-development of the externi or subnormal development of the interni, or to the fact that the externi have a more advantageous attachment to the globe than have the interni. Associated with either the one or the other of these conditions, there may be a deficiency in the third conjugate innervation center. While the chief cause—

the sole cause in most cases—may be in the excessive strength of the externi, the obliques may also enter into the causation, and that, too, without there being any imbalance of the obliques. If the obliques are hyper-developed, or if they are attached too far behind the equator, or if they are too short and tense, they will help the too strong externus to turn the eye out. If, in any case of exophoria, disease or injury should greatly reduce the vision of one eye, it will become exotropic in time. In anisometropia, if there is exophoria, the worse eye eventually will turn outward, in many cases. A congenitally low state of vision in one eye, when there is exophoria, will favor its transformation into exotropia. It is doubtful if "antipathy to binocular single vision" is as often a cause of exotropia as it is of esotropia.

The chief cause of many cases of exotropia has been traumatism; and, unfortunately for science, it has been operative traumatism. "Straightening crossed eyes in a minute" has most often resulted in a perpetual out-turning. But in the past, complete tenotomies of the interni for esotropia, performed by both general and ophthalmic surgeons, because they had been taught to do so by such masters as Dieffenbach and Graefe, resulted often, in a year or two, in an exotropia that was not comitant. Such a disaster has happened to every surgeon who has made many complete tenotomies of the

interni, even when he was most careful not to cut the check ligaments. It is true that exotropia has not followed all the complete tenotomies of the interni that have been made, else surgeons would have ceased, long ago, to attempt thus to relieve patients of one deformity simply to bring on them another, even more objectionable. Thanks to the long and strong insistence of Landolt, that advancements should supplant tenotomies, the days of complete tenotomies of the interni are numbered. Even Panas' operation cannot long delay the total abandonment of complete tenotomies for the relief of esotropia or any other form of heterotropia. Then no case of exotropia will result from surgery.

While comitant exotropia may show itself in only one eye, it is, nevertheless, a binocular trouble, which should not be forgotten at the time treatment is instituted. Exotropia always begins later in life than esotropia. Exotropia may be alternating early in the history of a case, but it soon becomes the fixed habit of one eye, usually the one that has conditions most favorable to mental suppression of images—a habit that is acquired by exotropes as well as by esotropes.

The complications of exotropia are errors of refraction (myopic refraction helps to cause exotropia); double hypertropia and double catatropia; hypertropia of one eye and catatropia of the other; and symmetrical or non-

symmetrical cyclotropia. Treatment of the complications must constitute a part of the treatment of the chief condition, and, for this reason, they should not be ignored in any case.

The amount of exotropia can be determined readily, by any one of the methods resorted to for measuring esotropia, by a reversal of every step.

Symptoms.—The symptoms of exotropia are objective and subjective. The only objective symptom is the disfigurement, which is greater or less, in proportion to the extent of the outward turning. Amblyopia, in many cases, is the only subjective symptom; and this—in some cases, at least—has been acquired by the power of mental suppression. Exophoria is attended, practically always, by reflex symptoms, as already shown; but reflex symptoms are rare in exotropia. The reflex symptoms found in a case of exotropia are due either to the nervous tension of the internus of the fixing eye or to some one or more of the complications. Exotropes who have been made so by complete tenotomies of the interni are more liable to show reflexes, and for the reason that the out-turned eye cannot move comitantly with its fellow. It is the generation of the excessive impulse—the unbalanced impulse—to force comitant movements that cannot be forced, which brings about the reflex disturbances. To

illustrate: Suppose that the right internus has been cut, resulting in a non-comitant exotropia. When the eyes are made to move to the right, there must be abnormal action of the fourth conjugate center; for the left internus, being opposed by an uncrippled externus, will require a greater impulse for a certain movement of its eye to the right than will the externus of the right eye, which is opposed by a crippled internus. It is the fourth conjugate brain-center that effects this rotation, and it cannot act normally under such a condition. In such a case, when the eyes are rotated toward the left, it must be through the fifth conjugate brain-center, which will attempt the impossible task of making the crippled right internus move its eye comitantly with the fellow eye whose externus is not crippled. The impossibility of accomplishing the task does not prevent the brain-center from undertaking it. Disturbance of one brain-center can excite sympathetic disturbance in any other brain-center.

One of the worst neurotic conditions that the author has ever seen was in a patient who had a non-comitant exotropia which had resulted from a complete tenotomy of his right internus, performed many years before. His case was diagnosed as an organic brain disease, and he was treated accordingly for two or more years without improvement. That his troubles were all reflex, and

that the cause was his non-comitant exotropia, cannot be doubted, for he recovered quickly after the enucleation of his exotropic eye, which operation was done at his own earnest solicitation; he even *demanded* that it should be done, believing, as he did, that this was his only chance. His belief that his troubles were referable to the condition of his right eye was based on temporary relief which he experienced two years previously from an advancement operation on the right internus, performed by the author, with an incomplete result as to position and movement. Later, an operation was done on the right superior rectus for a complicating hypertropia, with renewed relief of some of the symptoms that had again become prominent. Later, the author expected, and promised, to bring the right internus, atrophied as it was, still farther forward. The symptoms became aggravated again, and the patient returned for the promised operation. A colleague, Dr. J. A. Witherspoon, of Nashville, skilled in neurology, was called in consultation. The Doctor pronounced the case one of organic brain disease, the author agreeing with him. No other operation was attempted. The patient was placed entirely in the hands of the consultant, who treated him without results. In a few months the patient was induced to go to Battle Creek Sanitarium, where he remained for nearly two years without any marked

change in his condition, either for better or worse. It was while there that he insisted on the operation of enucleation, which was done.

The above case is thus fully reported to emphasize the point that a comitant heterotropia of one kind should never be converted into a non-comitant heterotropia of another kind, to avoid which one should be careful never to do a complete tenotomy of any rectus muscle for any condition.

In this connection it may be said that, in all probability, Dr. John Dunn, of Richmond, Va., was the first operator to enucleate one eye in which there was good vision, to relieve the patient of severe nervous symptoms caused by what was considered a hopeless muscle imbalance. The operation cured the patient. This case has not been reported.

Another case may be referred to also, somewhat like the two preceding cases as to results, though the method of obtaining them was unlike that resorted to in the other cases. This case was that of a young lawyer who suffered so much with his head and eyes that he contemplated giving up his profession, having failed to get relief from cylinders which he needed, from prisms which he did not need, and from ceiling-to-floor and wall-to-wall exercise, which, for some reason, he was unable to do for even one minute without suffering. There was

no heterophoria, but the muscles were "balanced in weakness," as shown by the fact that his abduction was two degrees; his adduction, less than ten degrees; his sub-duction and superduction, one degree. The vision of his right eye was $\frac{20}{XX}$; that of the left eye, $\frac{20}{XL}$. Every means that had been suggested by any one of the several ophthalmic surgeons whom he had consulted had been tried, and failure had resulted from all. At last the author advised him to have his left eye rendered useless. He consented, and the left lens, already slightly opaque, accounting for the reduced vision, was carefully needled, so as to render it densely opaque without effecting its solution. The comfort which he had been seeking came as a result of this operation. It has been one year and a half since the operation was done, and there has been no return of his symptoms. Nothing else than making the one eye blind, or removing it, could have cured him, except the shortening of all the recti muscles, and it is doubtful if that would have done it. These shortenings the author would have advised if the lens in his left eye had been perfectly transparent and vision had been good.

These three cases are reported here, though not properly connected, because of the results that followed so radical operations, after all other means had failed. These three patients, operated on by three different men,

would agree that it is better to go through life with only one eye than to have two eyes that would be a constant source of suffering. If relief can be obtained short of sacrificing one eye, so repulsive an operation as enucleation should be avoided.

Treatment of Exotropia.

The correction of myopia early in the history of an exotropia—that is, when there is exotropia in the near, but none in the far—by removing the pseudo-exophoric factor, may correct the exotropia, reconverting the exotropia into an intrinsic exophoria. But the correction of the exotropia by means of the concave lenses is not a cure, in the proper sense; the intrinsic exophoric factor must also be removed, and this can be done, in such a case, only by partial tenotomies of the externi or by shortenings or advancements of the interni.

In simple uncomplicated exotropia, at least three operations should be performed. Two operations on the deviating eye should be done first. One of these should be a partial tenotomy of the externus, so done as to lessen its tension without changing its plane of rotation—a central partial tenotomy; and at the same time the opposing internus should be either shortened or advanced, and in such a way as to increase its tension without changing its plane—a straight-forward shortening or a straight-

forward advancement. At any time after one week, a partial tenotomy of the externus of the fellow eye should be made, and in such a way as to lessen its tension without changing its plane—a central partial tenotomy. If these three operations do not properly relate the eyes, a fourth operation should be done, at any time after two to four weeks. This operation should be a shortening or an advancement of the internus of the good eye, and it should be so done as to increase its tension without changing its plane—a straight-forward shortening or a straight-forward advancement. A very slight simple exotropia may be cured by central partial tenotomies of the two externi, performed at the same time; but most cases will require three, if not four, operations. If these operations have been performed in the order and after the manner set forth above, the operator need have no fear that his case, which was comitant exotropia before the operations, will become non-comitant esotropia later; nor need he have any fear that a torsioning of the eyes will result. In exotropia of medium or high degree, the operation on the weak interni must be an advancement, for a shortening cannot produce enough effect.

An exotropia complicated with a double hypertropia, a double catatropia, or a hypertropia of one eye and a catatropia of the other, would require for its relief the same kind of operations as if there were no complication—

that is, the partial tenotomies of the externi should be central, so as to lessen tension without a change of plane; and the shortenings or advancements of the interni should be straight forward, so as to increase tension without a change of the plane of rotation. In the course of the treatment, the vertical heterotropia should be relieved in the manner to be shown in the study of hypertropia and catatropia, uncomplicated by cyclotropia.

If exotropia is complicated by plus cyclotropia only, the order of operating, as well as the method, should be changed. The two operations to be done first, and in immediate succession, should be performed on both externi, and should consist of a marginal tenotomy of each, the cut including the upper and central fibers, the lower fibers to remain intact. These operations would lessen the tension of both externi, and would lower their planes of rotation, so that, in their new relationship, they would tort the eyes in. This change of plane would also cause a double cataphoria. The operative effect on the two muscles should be as nearly equal as possible, so as to tort both eyes in alike and depress them equally. After these two operations, if some of the plus cyclotropia, as well as some of the exotropia, should remain, both interni should be shortened or advanced equally, and in such a manner as to elevate their planes of rotation. The amount of increase of tension and the extent of the elevation of the

planes would have to be gauged according to the best judgment of the operator. The end in view should be perfect control of the visual axes and the paralleling of the vertical axes with the median plane of the head. If the two marginal tenotomies should correct the whole of the plus cyclotropia, the remaining exotropia should be corrected by straight-forward shortening or advancement—first, of the internus of the deviating eye; and later, if necessary, of the internus of the good eye.

If exotropia is complicated with plus cyclotropia, right hypertropia, and left catatropia, the operations on the lateral recti should be done so as to alter their tension and change their planes of rotation, the latter only up to the point of a full correction of the plus cyclotropia. The operations should be done in the following order, with two or more weeks intervening: The first operation should be a marginal partial tenotomy of the externus of the hypertropic eye, including the upper and central fibers. The effect of this would be (1) to lessen its tension, so that the internus might draw the eye in; (2) lowering the plane so as to tort the eye in, to counteract the plus cyclotropia, and at the same time (3) turn the eye down for counteracting the right hypertropia. The second operation should be a shortening or an advancement of the left internus, so as to increase its tension and elevate its plane; and, that this may be done, not over half of the correction of

the main error and its complications should be attempted in the first operation. The effect of the second operation would be (1) to increase its tension so as to enable it to draw the eye in; (2) to tort the eye in, by means of the elevation of the plane, so as to counteract, if possible, the remaining plus cyclotropia; and (3) to elevate the eye, to still farther—and, if possible, entirely—relieve the remaining part of the left catatropia. If, for the farther relief of the exotropia (whether or not there may have remained from the first two operations some of the plus cyclotropia), it becomes necessary to operate on the internus of the right eye and the externus of the left eye, each of these operations would have to be done so as to alter tension without changing the plane of rotation—that is, the shortening or the advancement of the right internus would have to be straight-forward, and the partial tenotomy of the left externus would have to be central. The reason for this is clear: To elevate the plane of the right internus would help to correct any remaining plus cyclotropia, in itself desirable, but this would also elevate the eye—a thing not to be desired; to depress the plane of the left externus would correct any remaining plus cyclotropia, in itself desirable, but it would depress still farther the eye that is already too low.

It is so very rare that a minus cyclotropia is found complicating an exotropia, it is only necessary to say that,

when it does exist, both the order of operating and the method of doing each operation, looking toward a change of the muscle plane, should be the reverse of what has been advised when plus cyclotropia is the complication.

When exotropia is complicated by a double hypertropia and plus cyclotropia, it is probable that both complications are caused by the inferior obliques, and that these muscles have also entered largely into the causation of the exotropia. The operation most plainly indicated is a division of the inferior oblique of both the deviating eye and the fixing eye. If it were possible, in doing these operations, to leave some of its fibers uncut, it would be better. But a hook and scissors cannot be used, and the division must be effected by passing a Graefe knife above and beyond the muscle and between its origin and the course of the infraorbital vessels and nerves, with the cutting edge of the knife looking toward the orbital floor, then, bringing the knife down, dividing every structure between it and the orbital floor. Again, the author will say that he has done this operation on only one case, and the result was highly satisfactory. He would not hesitate to do it again in a case so well marked.

If the case is not sufficiently exaggerated to justify a complete division of the inferior obliques, or if these have been divided, but some of the main error with both of its complications remains, a marginal tenotomy of both ex-

terni should be done, including the upper and central fibers. This would lessen their tension, so as to allow the eyes to be drawn toward each other by the interni, and the lower uncut fibers would depress the eyes and would tort them in. To make shortenings or advancements of the interni with the view not only of increasing their tension, but also of changing their planes of rotation, would be wrong; for elevating these planes would raise the eyes still higher, while counteracting the plus cyclotropia—hurtful in one result, while helpful in the other. It is clear, therefore, that, in such a case, if the tension of the interni must be increased to still further correct the exotropia, the shortenings or advancements should be straight-forward.

At the meeting of the American Medical Association in Atlantic City, N. J., in 1900, L. Webster Fox, of Philadelphia, read before the section of ophthalmology a paper, entitled "A Simple Operation for Divergent Strabismus." He stated in this paper that he had put to a test the various accepted methods for correcting this error, and that he had noted the difficulties and many failures in his own practice, such as had been experienced by others. This led him to devise the method which he wished to describe, and for the reason that, through a period of eight years, it had given him satisfaction. At the author's request, Dr. Fox has furnished the cuts to illus-

trate the text. The method of procedure will be given in Fox's own words:

"The operation is divided into three parts, and is performed under cocaine: (1) tenotomy of both external recti muscles and stretching of conjunctiva and Tenon's capsule; (2) making the elliptical opening either on one eye or both; (3) suturing this opening.

"The details of operation are carried out as follows:

"1. Tenotomy of both external recti muscles, making an opening through the conjunctiva, over the insertion of the tendons. I then stretch Tenon's capsule until the cornea is well into the inner canthus; this is done on both eyes. Panas' method is to insert the hook under the muscle and apply pronounced traction, at the same time burying the cornea in the outer or inner canthus [inner, in exotropia]. The operation is performed under ether or chloroform, while in this method cocaine only is used. The stretching of Tenon's capsule is an important part of the operation. My method is as follows: The strabismus hook (which is a large one), flat on its side, is inserted in the opened conjunctiva and Tenon's capsule, and with considerable traction all the tissues are stretched inward until the cornea is buried in the inner canthus. The stretching of the upper tissue has, as can be readily understood, a tendency to rotate the eyeball to a certain degree and leave the conjunctiva

and Tenon's capsule intact below; to equalize the stretching, the point of the hook is reversed, and the lower conjunctiva and capsule stretched. In Panas' method the hook being placed under the external or internal muscle prevents rotation of the eyeball.

"2. With the retractor forceps I grasp the conjuctiva vertically, midway between the cornea and caruncle and

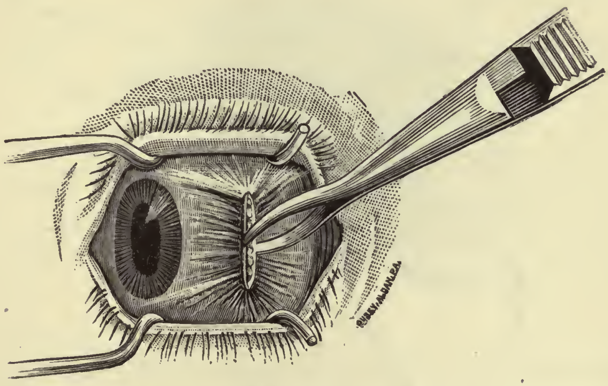

Fig. 53.

directly over the internal muscle, and draw upward the conjunctiva and as much of Tenon's capsule as I can. I raise the forceps two or three times to take up as much of the redundant tissue as my judgment dictates, and by this means one apparently is always successful in separating conjunctiva and overlying tissue from the muscle, if it be still present; then with curved scissors I cut

with one long sweep the upraised conjunctiva and capsule close to the eyeball, making an elliptic opening, exposing, at times, the attenuated muscle, and, if no muscle be present, then the clear sclerotic.

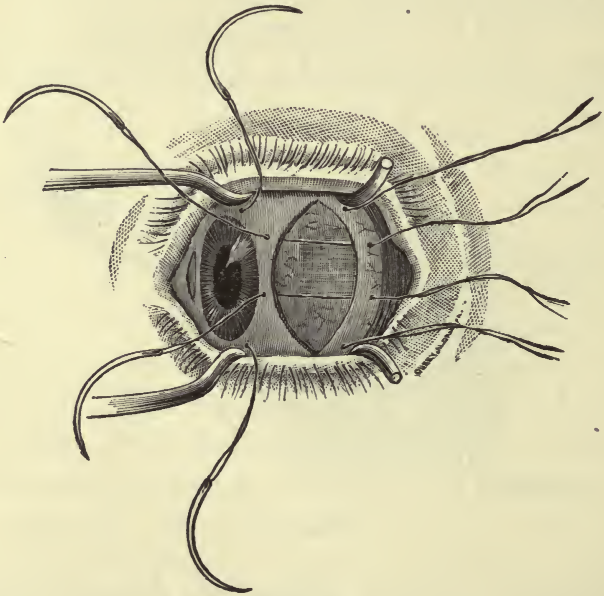

Fig. 54.

"This opening now extends in a vertical direction, beginning below the lower level of the cornea to a point above the same, its width over the muscle is about one full centimeter at its greatest diameter. The conjuctiva is then separated around this elliptic wound from its sub-

conjunctival tissues at all points—even around the cornea, if possible.

"3. The elliptic opening is brought together with four sutures. The upper suture is inserted through conjunctiva and Tenon's capsule and across under conjunctiva and Tenon's capsule midway between the insertion of the superior rectus muscle and the margin of the cornea;

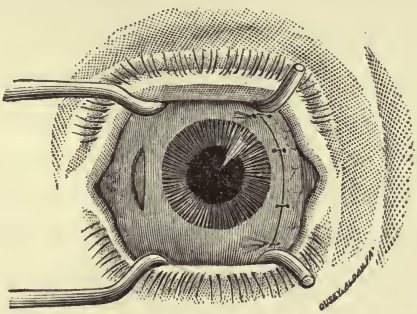

Fig. 55.

a similar suture is passed through the lower margin of the conjunctiva and brought out midway between the insertion of the inferior muscle and the margin of the cornea; this thread is then tied, and, in like manner, the upper thread; two more sutures are passed through the margin of the lips of the wound and united.

"This constitutes the details of the operation. The object of the operator should be to produce from one to four millimeters of convergence, which disappears during

cicatrization. When the defect is not more than two or three millimeters, I have performed an external tenotomy on both and stretched Tenon's capsule, with excellent results, without taking out the elliptic section, especially in those cases where the eyes could be held by the patient at fixed convergence at ten inches."

Fox's operation has been thus described, in his own words, for the reason that it is probably the equal of Panas' operation, if not superior to it, for exotropia. While it may be comparatively safe in exotropia, it certainly would be very dangerous in esotropia; but even in exotropia there is danger that a complete tenotomy may cripple the comitant lateral movements of the eyes—a danger never encountered when the stronger muscle is partially divided, without any stretching, and the weaker muscle is shortened or advanced.

The form of exotropia that most urgently demands relief is the non-comitant exotropia which has resulted from complete tenotomies for esotropia. In these cases the externi, which were never possessed of too much intrinsic strength, should not be even partially cut, but the whole effect should be accomplished by advancement of the internus that had been allowed to retract too far. In these cases all the complications must be considered, and the advancements should be governed accordingly.

Hypertropia and Catatropia.

These conditions practically always exist as complications of either esotropia or exotropia, and not infrequently are associated with cyclotropia. Hypertropia may be double, and catatropia may be double, or there may be a hypertropia of one eye and a catatropia of the other. If there is double hypertropia without cyclotropia, the error is caused by the conjoined action of the superior recti and the inferior obliques, both of which elevate the eye, while the in-torting action of the superior rectus is counteracted by the out-torting action of the inferior obliques.

If there is double hypertropia with minus cyclotropia, the chief factors in its production are the superior recti, aided, possibly, by interni whose attachments are too high.

If there is double hypertropia with plus cyclotropia, the chief factors are the inferior obliques, aided, possibly, by externi that are attached too high.

Double catatropia, if caused by both the inferior recti and the superior obliques, will show no cyclotropia; if caused by the inferior recti alone, or with the aid of interni that are attached too low, there will be plus cyclotropia also; if caused by the superior obliques alone, or with the aid of externi whose attachments are too low, there will be minus cyclotropia also.

When there is hypertropia of one eye with catatropia of the other, there will be no cyclotropia if the hypertropia is caused by the conjoined action of the superior rectus and the inferior oblique, and the catatropia is caused by the united action of the inferior rectus and the superior oblique.

If the hypertropia of the one eye is caused by the superior rectus alone, or with the aid of a too high internus, there will be minus cyclotropia; and if the catatropia of the other eye is caused by the inferior rectus alone, or with the aid of a too low internus, there will be plus cyclotropia—the two eyes together would have parallel cyclotropia.

If the hypertropia of the one eye is caused by the inferior oblique alone, or with the aid of an externus that is attached too high, there will be also a plus cyclotropia; and if the catatropia of the other eye is caused by the superior oblique alone, or with the aid of an externus that is attached too low, there will be also a minus cyclotropia—the two eyes together would show parallel cyclotropia.

If there is hypertropia of one eye with catatropia of the other, and the complication is plus cyclotropia of both eyes, the cause of the hypertropia is the inferior oblique, and the cause of the catatropia is the inferior rectus; or, if the complication is minus cyclotropia, the

cause of the hypertropia is the superior rectus, and the cause of the catatropia is the superior oblique.

The cause of the vertical heterotropias is in the muscles that are concerned in elevating and depressing the eyes, aided in some cases by the lateral muscles that are attached too high or too low. For the first year or two the want of harmony between these muscles is shown by some form of vertical heterophoria, which, especially when associated with some form of imbalance of the laterally acting muscles, becomes transformed into a vertical heterotropia at the same time that the lateral heterophoria becomes transformed into lateral heterotropia. Hypertropia and catatropia rarely exist alone. They are comitant in character, except when they are the result of operations or caused by paralysis.

The disfigurement of the individual is the objective symptom; and the subjective symptoms are those already mentioned in connection with the study of the lateral heterotropias. Reflex neuroses are not often connected with the comitant form; but when they do exist, their cause is abnormal nervous tension of the weaker muscle of the fixing eye. But the non-comitant hypertropia or catatropia—nearly always the latter, for the reason that a complete tenotomy of a superior rectus for a hyperphoria is more often done than a complete tenotomy for a cataphoria—often causes

severe reflexes; besides, a non-comitant catatropia, resulting from a complete division of a superior rectus for a hyperphoria, in an adult, is always attended by diplopia. At that age mental suppression is impossible.

These errors can be measured more easily by the phorometer than by any other method, but the perimeter and the tape methods (the graduated tape to be held vertically) can be resorted to.

Treatment of Vertical Heterotropia.

In the discussion of the treatment of esotropia and exotropia it has been shown that, when hypertropia and catatropia are the only complication, each condition must be treated as though the other did not exist—that is, every offending muscle must have its tension altered without a change of plane. In the same manner must uncomplicated vertical heterotropias be treated. If the error is a double hypertropia, a central partial tenotomy of each superior rectus should be done. The effect should be equally divided between the muscles, so as to lower the eyes the same number of degrees. If the condition is an uncomplicated double catatropia, a central partial tenotomy of both inferior recti should be done; but care should be taken not to do too much, for the reason that a slight double catatropia is much to be preferred to a very slight double hypertropia.

A double hypertropia complicated by plus cyclotropia is caused by the inferior obliques. If these two errors are very high in degree, and especially if there is want of converging power, the conditions would be better corrected by cutting both inferior obliques. These operations would correct not only the double hypertropia and the plus cyclotropia, but would also give an increase of converging power. If these combined errors are not so high in degree, or if high in degree and there is little or much esotropia, a division of the inner and central fibers of both superior recti would be indicated; for these operations would correct the double hypertropia and the plus cyclotropia and at the same time would lessen convergence.

A double hypertropia complicated by a minus cyclotropia is caused by the two superior recti, and the operation to be done is a marginal tenotomy of both these muscles, dividing the temporal and central fibers. In such a case there is practically always some esotropia also, which will be slightly increased by these operations; but the latter can be treated as set forth under the head "Esotropia."

A double catatropia complicated by a plus cyclotropia is caused by the inferior recti alone, and should be relieved by a division of the temporal and central fibers of both these muscles. If in such a case there is want of

converging power, this would be helped by these operations; but if there is an excess of convergence, this will be made greater. How to deal with such a case has been set forth already.

The most common form of vertical heterotropia is hypertropia of one eye and catatropia of the other. If there is no complicating cyclotropia, the first operation should be a central partial tenotomy of the superior rectus of the hypertropic eye, the aim being to accomplish more than half the correction, rather than less; and the second operation, after from two to four weeks, should be a central partial tenotomy of the inferior rectus of the catatropic eye, with the view of placing the visual axes in the same plane. These operations will result only in lessening the tension of the muscles that are too strong. If some of the old errors should remain, the third operation should be a straight-forward shortening of the inferior rectus of the hypertropic eye. These three operations should correct the most aggravated vertical error; but a fourth operation could be done—viz., a straight-forward shortening of the superior rectus of the catatropic eye.

Hypertropia of one eye and catatropia of the other, complicated by a plus cyclotropia, should be corrected by a marginal partial tenotomy, including the nasal and central fibers, of the superior rectus of the hypertropic

eye; and a marginal partial tenotomy, including the temporal and central fibers, of the inferior rectus of the catatropic eye.

Hypertropia of one eye and catatropia of the other, complicated by parallel cyclotropia—plus in one eye and minus in the other—would require one method of procedure if the hypertropic eye had the plus cyclotropia, and a very different method if the hypertropic eye had the minus cyclotropia. In the former case the marginal tenotomy of the superior rectus of the hypertropic eye should include the nasal and central fibers, and the marginal tenotomy of the inferior rectus of the catatropic eye should include its nasal and central fibers; while in the latter case the tenotomy would include the temporal and central fibers of the superior rectus of the hypertropic eye and the temporal and central fibers of the inferior rectus of the catatropic eye.

CYCLOTROPIA.

Cyclotropia is an actual loss of parallelism between the vertical axes of the eyes and the fixed median plane of the head. This condition probably never exists alone, though it is often found in connection with other forms of heterotropia, as has been shown already. It may be, however, the chief condition in some cases, the lateral or vertical deviations of the visual axes being complications;

but far more often the cyclotropia is a complication of the vertical and lateral deviations.

There are two classes of cyclotropia—namely, similar and dissimilar. In the former class the cyclotropia is plus or minus in both eyes, while in the latter class the error is plus in one eye and minus in the other. The former might be termed "non-parallel cyclotropia"—that is, the vertical axes are either divergent or convergent; the latter might be termed "parallel cyclotropia"—that is, the vertical axes are inclined one toward, and the other from, the median plane. Cases of parallel cyclotropia are not often found; and of the non-parallel class, plus cyclotropia is far more common than minus cyclotropia.

In parallel cyclotropia, if the minus error is in the right eye and the superior oblique is the cause, in the sense of being too strong, the complication for that eye will be catatropia; but if the superior rectus is the cause, the complication will be hypertropia. The plus cyclotropia of the left eye will be complicated with hypertropia if the inferior oblique is the cause, and catatropia will be the complication if the inferior rectus is the cause. In esotropia, which may complicate parallel cyclotropia, the internus of the right eye, if attached too high, will aid in the production of the minus cyclotropia, and, in some cases, may be the chief cause of the minus cyclo-

tropia; while the internus of the left eye, if its attachment is too low, will aid in the production of the left plus cyclotropia. A too low right externus would be a causative factor of the minus cyclotropia, and a too high left externus would help to cause the plus cyclotropia of this eye.

In plus cyclotropia of both eyes, the error is caused by both inferior obliques or by both inferior recti. If the inferior obliques cause the error, the necessary complication will be double hypertropia; and if the inferior recti are the cause, the necessary complication will be double catatropia. The interni, with their attachments too low, can help the inferior recti in the development of plus cyclotropia; and the externi, with their attachments too high, can aid the inferior obliques in the causation of the plus cyclotropia.

Minus cyclotropia of both eyes can be caused by the superior obliques alone, when the complication will be double catatropia; it can also be caused by the superior recti, when the complication will be double hypertropia. Externi that are too low can help the superior obliques in the production of minus cyclotropia, and interni that are too high can aid the superior recti in the production of minus cyclotropia.

Plus cyclotropia of one eye, with hypertropia, is caused by the inferior oblique; plus cyclotropia of the

other eye, with catatropia, is caused by the inferior rectus.

Cyclotropia, of whatever kind, can be detected and measured by means of the cyclo-phorometer, used as in the investigation of cyclophoria. Because of the amblyopia that usually exists in one eye, the red glass should be placed in the cell behind the rod that is before the better eye. The prism of five degrees should be placed in the cell behind the rod that is in front of the amblyopic eye, base either up or down—in the former position, if this eye is hypertropic; in the latter position, if it is catatropic. If the red streak of light is below, and the two streaks converge at the ends corresponding to the red glass, there is plus cyclotropia; if they converge at the other ends, there is minus cyclotropia. Turning the rods in the directions that will parallel the streaks, and at the same time make them appear to be horizontal, measures the error; and the pointing of the index also names the error. If the two stand in the nasal quadrant, the error is plus; if they stand in the temporal quadrant, the error is minus.

Cyclotropia, like the other forms of heterotropia, is alternating—that is, the fixing eye, whichever it may be, will have its vertical axis parallel with the median plane of the head, while the vertical axis of the other eye will be torted out or in, as the case may determine.

It is also comitant, the angle being the same in all positions of the eyes.

Cyclotropia, caused by paralysis, or paresis, and operations, is non-comitant, and will be attended by most annoying symptoms. The symptoms of comitant cyclotropia are those common to the other forms of comitant heterotropia, including the loss of vision in one eye, caused by mental suppression. Reflex symptoms are caused by nervous tension of the weaker oblique of the fixing eye, that the vertical axis may be made parallel with the median plane of the head.

Treatment of Cyclotropia.

When cyclotropia is a complication of esotropia, exotropia, hypertropia, and catatropia, it should be treated as has been set forth already. Here it is necessary to speak of the treatment of cyclotropia when it is the chief error; it rarely exists alone. If there is much plus cyclotropia, complicated by double hypertropia, but no marked lateral error exists, the operative effect should be equally divided between the two eyes. Either the two inferior obliques should be divided completely (for the reason that a partial division of these muscles seems impossible) with the Graefe knife; or a marginal tenotomy of both superior recti should be done, consisting of a division of the nasal and central fibers of

each, leaving uncut the temporal fibers. The results of the operation on the superior recti would be the same in kind, if not in degree, as those done on the inferior obliques—namely, the two eyes would be partly, if not wholly, relieved of the outward torsion, and they would be relieved more or less of the double hypertropia. In the absence of any lateral deviation, the only remaining muscles to be subjected to operations are the inferior recti, whose nasal fibers should be shortened or advanced equally. The operations on the inferior recti would correct more or less of the plus cyclotropia and the double hypertropia.

Plus cyclotropia complicated by hypertropia of the right eye and catatropia of the left eye, should be treated first by one or the other of two operations on the right eye—that is, either the inferior oblique should be cut, or a marginal partial tenotomy, including the nasal and central fibers, should be done on the superior rectus. Either of these operations would correct wholly or in part both the plus cyclotropia and the hypertropia of this eye. The next step would be to divide the temporal and central fibers of the inferior rectus of the left eye, which would correct wholly or in part both the plus cyclotropia and the catatropia of this eye. If, after these operations have been done, there should remain some of both the plus cyclotropia and the hypertropia of the right

eye and catatropia of the left eye, one other operation should be done on each eye—namely, the nasal margin of the right inferior rectus and the temporal margin of the left superior rectus should be either shortened or advanced.

Plus cyclotropia uncomplicated by any other deviation, should be relieved by either a nasal marginal tenotomy of both superior recti or by a nasal marginal advancement or shortening of both inferior recti; or, in cases demanding it, both operations should be done on each eye. Since a double catatropia would result, necessarily, from either marginal tenotomies of the superior recti or marginal shortenings or advancements of the inferior recti, the former operation should be preferred, for the reason that it is both more easily done and less annoying afterwards to the patient. In those cases in which sub-duction is greater than normal (more than three degrees), after the nasal marginal tenotomies of the superior recti have failed to correct the plus cyclotropia, temporal marginal tenotomies of the inferior recti should take the place of the nasal marginal shortenings or advancements.

Minus cyclotropia complicated or uncomplicated is so rare that its treatment may be dismissed with the statement that the part of a superior or inferior rectus that should be cut for plus cyclotropia should be advanced or shortened for a minus cyclotropia, and the part of these

muscles that should be advanced or shortened for a plus cyclotropia should be cut for a minus cyclotropia. The same holds true also as to operations that might be indicated on the lateral recti, when errors of these muscles complicate minus cyclotropia. The superior oblique has probably never been divided, nor should this be done, for a minus cyclotropia.

In the discussion of the treatment of the various forms of heterotropia, much has been taught in this chapter that cannot be appreciated by the reader who is not well grounded in the principles set forth in Chapter I. In this department of ophthalmology theory directs practice and practice sustains theory. Every operation on the extrinsic ocular muscles should be done with the view of enabling the superior and inferior recti to *plane* the visual axes, the interni and externi to so control these axes in this plane as to make them *intersect* at the point of view, and the obliques to *parallel* the vertical axes of the eyes with the median plane of the head. In accomplishing these aims, operations should be so done as not to reduce below the normal the duction and version power of a single muscle.

CHAPTER XI.

PARALYSIS AND PARESIS OF THE OCULAR MUSCLES.

A BRIEF review of the nerve supply is essential to a clear understanding of paralysis or paresis affecting one or more of the ocular muscles.

THE THIRD NERVE (mortor oculi).—This nerve sends fibers to the superior, inferior, and internal straight muscles, and to the inferior oblique; it also supplies the muscle that elevates the upper lid; and through the medium of the ciliary ganglion it sends fibers to the sphincter of the iris and to the ciliary muscle. Its nucleus of origin is in the posterior part of the floor of the third ventricle, and in the floor of the aqueduct of Sylvius. There is a nucleolus of origin for those fibers of this nerve that finally must terminate in the individual muscle to be controlled by it. Of these nucleoli the most anterior one is connected with the sphincter of the iris; the one nearest it is connected with the ciliary muscle; and the next one, in order, is connected with the internal rectus. The order of the nucleoli that are

connected with the other muscles supplied by the third nerve is not so well understood. Some optic nerve fibers—these doubtless come from the macula—are connected with the nucleus of origin of the oculo-mortor nerve, and thus is established the reflex relationship between the retina and the muscles supplied by the third nerve. From each of these nucleoli, fibers go, through the internal capsule, to higher brain-centers, and are there connected with fibers from nucleoli in the nucleus of origin of the other nerve of the pair.

To illustrate: The first conjugate brain-center—the one that causes both superior recti to rotate the eyes up—must have connected with it fibers that come from the nucleolus on the right side, which is connected with the right superior rectus, and the nucleolus on the left side, which is connected with the left superior rectus; likewise the nucleoli—the one on the one side of the brain; the other, on the other side—connected with their respective internal recti, must each send fibers to the third conjugate brain center (the center of convergence). Thus the connection of all the conjugate brain-centers with corresponding nucleoli at the base of the brain might be traced. It appears evident that some of these connecting fibers, on their way to the higher centers—the conjugate centers—must cross from one side of the brain to the other.

THE FOURTH NERVE.—This supplies only one muscle, the superior oblique. Its nucleus of origin is immediately behind that of the third nerve. With this nucleus there is connected, most likely, some optic nerve fibers, to establish the reflex relationship between the retina and the superior oblique. From these nuclei—the one on the one side of the brain; the other, on the other side—fibers must go to form a common connection with the sixth conjugate brain-center; and from the right nucleus, fibers must go to form a common connection, in the eighth conjugate brain-center, with fibers from the nucleolus controlling the left inferior oblique; likewise fibers must go from the nucleus for the fourth nerve on the left side to connect, in the ninth conjugate center, with fibers from the nucleolus on the right side that controls the right inferior oblique. Again, it is evident that, to reach these conjugate centers, some fibers must cross from one side of the brain to the other.

THE SIXTH NERVE.—This supplies only one muscle, the external rectus of the corresponding side. This nucleus is behind that of the fourth nerve, and is separated from it by the nucleus of origin of the fifth nerve. Fibers from the nucleus controlling the right externus must go to the fourth conjugate brain-center, to connect with fibers from the nucleolus that controls the left internus; and, in like manner, fibers from the nucleus that

controls the left externus must connect, in the fifth conjugate brain-center, with fibers from the nucleolus that controls the right internus. Again, it appears that some fibers must cross from one side of the brain to the other, that these connections may be formed. It is reasonable to suppose that some optic nerve fibers are also connected with the nucleus of the sixth nerve, to establish the reflex relationship between the retina and the externus.

CAUSES.—Paralytic or paretic heterotropia may be caused by disease or injury of the muscle, or muscles, affected; by disease or injury involving the nerve trunk; by disease of the nucleus at the base of the brain; by disease in the internal capsule or corona radiata; and by disease or injury of a conjugate brain-center in the cortex.

Occasionally children are born with paralysis of one or more ocular muscles.

The disease that most often causes paralysis or paresis of the ocular muscles is syphilis. The muscles most frequently involved, when syphilis is the cause, are those supplied by the third nerve; but the superior oblique and the external rectus may suffer from the same cause. The history of the case will show whether syphilis is the probable cause. Ocular paralysis is one of the remote results of syphilitic infection.

Rheumatism affecting the muscle itself or involving

the nerve in its course is not infrequently the cause of ocular paralysis or paresis. The external rectus is the muscle that most frequently suffers from this cause.

A cold contracted from undue exposure to dampness, to a draught, or any other causative agent, may cause, in some inexplicable way, paresis or even paralysis of any one of the ocular muscles.

Tumor, or other disease of the internal capsule and the corona radiata, will cause paralysis of conjugate movements, but not paralysis of the muscles; duction power, which is reflex in character, will not be involved, but the verting power, which is volitional, will be impaired or lost. In such cases, symptoms referable to other parts are always associated with the eye symptoms.

Injury or disease of the cortex, involving any one of the nine conjugate centers, will result in paralysis or paresis of one muscle connected with each eye; but the paralysis will show itself in the absence of verting power, with no loss of duction power. To illustrate: If the third conjugate center alone is involved, there can be no convergence, but because of freedom from disease of the fourth and fifth conjugate centers the two eyes can be made to turn harmoniously to the right or to the left; and adduction, which is reflex, will be unimpaired.

Disease or injury of the orbit involving the parts

around the sphenoidal fissure, disease in the orbital cavity behind the eye, and disease or injury of the muscles themselves, can cause paralysis of any one or several of the orbital muscles.

Individual Forms of Paralysis.

(1) The Third Nerve.—If the cause is in the nucleus or in the course of the nerve before it divides into its several branches, the following conditions will be present: (*a*) Ptosis; (*b*) the eye will be turned out more or less by the unopposed externus, and it cannot be rotated in; (*c*) the eye will be turned slightly down and will be torted in by the unopposed superior oblique; the eye cannot be turned upward, for both elevators—the superior rectus and the inferior oblique—are involved, and it can be turned downward only slightly by the superior oblique, for the chief depressor—the inferior rectus—is powerless; (*d*) the pupil will be dilated and the accommodation will be suspended. There will be neither headache, nausea, nor dizziness; for the fallen lid cuts off the light from the eye, and the brain-centers—centers in the cortex—are not excited.

If the disease involves only one branch after it leaves the main nerve, only one muscle will be affected. If the diseased branch is the one supplying the muscle that elevates the upper lid, the only symptom will be ptosis.

If the involved branch is the one supplying the internus, both adduction and adversion will be impaired or abolished, the eye being turned out; and because of the absence of ptosis there will be crossed diplopia, associated with headache, nausea, and dizziness, due to excitation of brain-centers. If the affected branch is the one supplying the inferior rectus, sub-duction will be impaired or absent, and sub-version by the superior oblique will be only slight; and, for the same reason given above, there will be diplopia in the lower field, headache, nausea, and dizziness. If the involved branch is the one supplying the superior rectus, superduction will be impaired or lost, and superversion by the inferior oblique will be only slight; and there would be diplopia in the upper field, headache, nausea, and dizziness. If the branch affected is the one supplying the inferior oblique, superduction (by the superior rectus) will probably be unimpaired, and superversion will be only slightly lessened; and there will be diplopia in the upper field, headache, nausea, and dizziness on attempting to look up, as would be true, also, when the superior rectus is paretic. The symptoms caused by paresis of the inferior rectus (and by paresis of the superior oblique, as will be shown later) are always more pronounced, for the reason that we look down more than we look up. If the branch implicated is the one going to the ciliary ganglion, thence to the

ciliary muscle and the sphincter of the iris, there will be complete loss of accommodation and full dilatation of the pupil; but if the ciliary ganglion itself is the involved part, there will be complete loss of accommodation, but the pupil will not be fully dilated. Both the sphincter of the iris and the dilator fibers will be paralyzed, hence partial dilatation, but complete inactivity of the pupil. The symptoms will be: Dread of light, inability to see near objects well, and pain referable to the eye.

(2) THE FOURTH NERVE.—Since this nerve supplies only the superior oblique, the symptoms are the same, whether the disease is at the nucleus of origin, or in the course, of the nerve. The eye is torted out by the unopposed inferior oblique; sub-version is limited, but sub-duction is probably not much impaired. There is always diplopia in the lower field. Nausea, vomiting, dizziness, and headache are nearly always pronounced.

(3) THE SIXTH NERVE.—Since this nerve supplies only the external rectus, the symptoms are always the same, whether it is diseased at its nucleus or in its course. The eye will be turned in, and both abduction and abversion will be abolished. There will be homonymous diplopia. There being no ptosis to cut off light from the affected eye, the cortical centers will become excited, and there will be headache, nausea, and dizziness when attempting to look toward the corresponding side.

It is only when there is extensive disease at the base of the brain, or disease involving all the structures in the sphenoidal fissure, or extensive disease in the orbit itself, that paralysis of all the muscles of one eye is possible. The symptoms of such a condition would be immobility of the eye in any direction; protrusion of the eye, even when the disease causing it is not in the orbit, for there would be relaxation of all the external muscles; diplopia would be pronounced in all directions (unless the optic nerve has been involved in the disease process within the cranium), were it not for the fact that the upper lid usually falls far enough down to cover the pupil; the ptosis would be complete, were it not modified by the protrusion of the globe; and, finally, the accommodation would be suspended and the pupil dilated. An ophthalmoplogia externa, without associated paralysis of the ciliary muscle and sphincter of the iris, is inconceivable, and that, too, whether the disease causing it is intracranial or interorbital. On the contrary, paralysis of the muscles within the eye may be unassociated with paralysis of the external muscles.

DIAGNOSIS.—There can never be any doubt as to what rectus muscle is involved when the paralysis is complete; but when there is paresis, it is often a difficult matter to determine to which eye the affected muscle belongs and what muscle is involved, for in some of these cases

there is no perceptible squint, and apparently no limitation of movement. The unfailing test for paresis and (were it necessary) for paralysis is the diplopia test. This test will always be responded to in the direction of action of the affected muscle, and it invariably determines the eye to which the affected muscle belongs and unerringly points to the paretic muscle. For the laterally acting muscles the following rule may be formulated: The candle will appear single in the left field if the affected muscle is a right vertor, but will be doubled in the right field, and *vice versa* if the affected muscle is a left vertor; *the eye to which the affected muscle belongs will see the candle that is farthest removed* (*the false candle*), *and the affected muscle is on that side of this eye corresponding to the direction of doubling.* If the doubling is to the right, the paretic muscle is a right vertor, and is, therefore, either the right externus or the left internus. If the right eye sees the candle farthest removed, it is the right externus; but if the left eye sees the false light, it is the left internus. Nothing could be more easily accomplished than the complete diagnosis of paresis of a right vertor or a left vertor.

Although there are two sub-vertors and two super-vertors for each eye, the determination of the question, "To which eye belongs the paretic muscle?" is as easy as can be; and the difficulty in the way of finding the

involved muscle is only apparent. If the affected muscle is a sub-vertor, the candle will appear single above, but double below, the horizontal plane, and *vice versa* if the affected muscle is a supervertor. The following is the rule for finding the eye to which the affected muscle belongs and for locating the paretic muscle: *The eye to which the paretic sub-vertor or supervertor belongs sees the candle that is farthest removed (either above or below) from the horizontal plane, and the direction of the leaning of the false candle determines whether it is a straight or an oblique muscle that is involved.* If the doubling is below the horizontal plane and the false candle leans toward the same side, the inferior rectus is the paretic muscle; if it leans toward the opposite side, the superior oblique is the paretic muscle; but if the doubling is above the horizontal plane and the false candle leans toward the corresponding side, the inferior oblique is paretic; if it leans toward the opposite side, the superior rectus is paretic.

The accompanying cuts illustrate perfectly the rules given above. In the cuts illustrating paresis and paralysis of the right and left vertors, the doubling is represented as existing when the vertical plane has been reached, the distance between the false and the true candles increasing as the candle is carried farther in the

direction of action of the affected muscle. This is always true in paralysis, but in paresis the doubling may not occur, in passing from the field of fusion into the field of diplopia, until the vertical plane has been passed. Likewise, in the cuts representing paralysis and paresis of the sub-vertors and supervertors, the doubling is represented as having occurred before reaching the horizontal plane, in passing from the fusion field into the field of diplopia.

Fig. 56.

Fig. 56 illustrates paralysis or paresis of a right vertor, either the right externus or the left internus. If the right eye sees candle *b*, the affected muscle is the right externus; but if the left eye sees candle *b*, the affected muscle is the left internus. A red glass before either eye shows quickly which eye it is that sees the false candle; covering either eye with a card will also show which eye it is that sees candle *b*.

The false candle may be above or below the true, or of the same height as shown in the cut, depending on the state of imbalance or balance of the vertically acting

muscles. A leaning of the false candle will appear whenever there is a cyclophoria.

Fig. 57 illustrates paralysis or paresis of a left vertor, either the left externus or the right internus. If the left eye sees candle *b*, the affected muscle is the left externus; but if the right eye sees candle *b*, it is the right internus.

The false candle in paralysis of a right or a left vertor is not always parallel with the true candle. When this is true, the direct antagonist of the paralyzed

Fig. 57.

muscle has not an ideal attachment to the globe; its attachment is either too high or too low. When the healthy muscle is an internus, if the false candle leans toward the side of the affected eye, its attachment is too high, or there is minus cyclophoria; but if the false candle leans toward the opposite side, its attachment is too low, or there is a plus cyclophoria. Just the opposite is true when the healthy muscle is an externus.

The false candle may be higher or lower than, or even with, the true, depending on the state of imbalance or balance of the vertically acting muscles.

Fig. 58 and Fig. 59 illustrate paralysis of a sub-vertor muscle of either one eye or the other. Below, in parallel columns, will be shown the significance of each cut. Inclination toward the opposite side points to the superior oblique, while inclination toward the same side points to the inferior rectus:

Fig. 58.

Fig. 58 is illustrative of paralysis of either the superior oblique or the inferior rectus of the eye that sees candle *b*. If the right eye sees it, the affected muscle is the inferior rectus; but if the left eye sees it, the affected muscle is the superior oblique.

Fig. 59.

Fig. 59 is illustrative of paralysis of either the superior oblique or the inferior rectus of the eye that sees candle *b*. If the right eye sees it, the affected muscle is the superior oblique; but if the left eye sees it, the affected muscle is the inferior rectus.

In either case the false candle may be to the right or left of the true, depending on the relationship between the lateral recti muscles.

Fig. 60 and Fig. 61 illustrate paralysis of a supervertor muscle of either one eye or the other. Below, in parallel columns, will be shown the significance of each cut. Inclination toward the opposite side points to the superior rectus, while inclination toward the same side points to the inferior oblique:

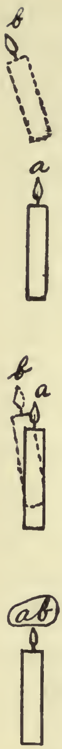

Fig. 60.

Fig. 60 is illustrative of paralysis of either the superior rectus or the inferior oblique of the eye that sees candle *b*. If the right eye sees it, the affected muscle is the superior rectus; but if the left eye sees it, the affected muscle is the inferior oblique.

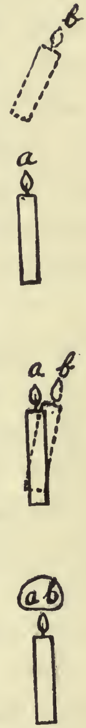

Fig. 61.

Fig. 61 is illustrative of paralysis of either the superior rectus or the inferior oblique of the eye that sees candle *b*. If the right eye sees it, the affected muscle is the inferior oblique; but if the left eye sees it, the affected muscle is the superior rectus.

As in paresis or paralysis of the sub-vertors, the false candle may be to the right or left of the true, depending on the relative strength of the laterally acting muscles.

In making a diagnosis of paralysis or paresis of the ocular muscles, by means of the diplopia test, the candle need be carried only in the four cardinal directions—that is, the head should be erect; and in testing for paresis of the right and left vertors, the candle should be carried only along the extended horizontal plane of the head directly to the right and left of the vertical plane; and in testing for paresis of the sub-vertors and supervertors, the candle should be carried only in the extended median plane of the head, above and below the horizontal plane.

For detecting paralysis or paresis of the sub-vertors and supervertors, nothing serves better than a horizontal line at a distance of twenty feet. If the sub-vertors are at fault, elevating the head, while still looking at the line, will cause it to double, the false line appearing below the true. If the false line leans toward the corresponding side, the affected muscle is the inferior rectus; but if it leans toward the opposite side, the affected muscle is the superior oblique.

When a right vertor or a left vertor is paralyzed, the resulting deviation might be mistaken for comitant lateral heterotropia. This may be avoided in two ways —first, by a test of the verting power, when the affected eye will always lag behind its fellow if the two eyes are turned in the direction of action of the paretic muscle, whereas, in comitant squint, the deviating eye moves

always through as great an arc as the fixing eye; secondly, by covering the eyes alternately, the secondary deviation will always be greater than the primary, when there is paralysis. But in comitant squint the secondary and the primary deviations are always the same.

In paralytic squint there is always diplopia in one part of the field, with binocular single vision in the opposite part; while in comitant squint there is no diplopia in any part of the field.

A very good diagnostic feature is the pose of the head in cases of paralysis of an orbital muscle. In paralysis of a lateral rectus muscle, the face is always turned in the direction of action of the affected muscle—that is, if a left vertor is paralyzed, the face will be turned to the left in the interest of binocular single vision, and *vice versa* if a right vertor is paralyzed; if a sub-vertor is paralyzed, the face will be depressed; and if a super-vertor is paralyzed, the face will be elevated.

In "paralysis of motion, rather than of muscle," duction power, which is reflex in the sense that it is not volitional, is not involved. This statement covers all the conjugate brain-centers from the first to the fifth, inclusive—those centers that are concerned with the recti muscles. Since there is no voluntary action of the obliques, the cortical centers (if there be such) governing them must act independently of the will. These centers

are the sixth, seventh, eighth, and ninth. That these conjugate centers for the obliques may be involved in pathologic changes must be conceded Since the object of the sixth and seventh centers is to prevent diplopia, on looking down and up, respectively, these correspond perfectly in action with the reflex centers of the recti that are also concerned with the prevention of diplopia when images are displaced by prisms; therefore they ought not to be affected in disease of the cortex. The eighth and ninth centers are not concerned with the prevention of diplopia; but, what is probably of as much importance, they are concerned with the steadying of all objects in the field of vision whenever the eyes are voluntarily moved in an oblique direction. For instance, when the gaze is directed up and to the right, or down and to the left, the eyes would be torted to the right, were it not for the eighth conjugate center, when all objects would be made to appear to incline to the left from their real position, their inclination corresponding precisely with the degree of torsioning. This is prevented by the eighth conjugate center, which maintains the parallelism between the vertical axes of the eyes and the median plane of the head in such a voluntary rotation. It appears, therefore, that disease of this center would be attended by a wheel-like movement of objects whenever the visual axes are made to move up and to the right, or

down and to the left, which appearance would not be if the gaze were directed up and to the left, or down and to the right. But if the ninth conjugate center were involved in pathologic change, the wheel-like movement of objects would be observed only when the gaze is up and to the left, or down and to the right. In neither case would there be diplopia.

Should the sixth conjugate center be involved, on looking down at a candle it would appear double, the one seen by the right eye leaning to the left and the one seen by the left eye leaning to the right; the diplopia would be attended by dizziness and nausea. In the upper field there would be no diplopia.

Should the seventh conjugate center become diseased, the diplopia would be in the upper field, and the candle seen by the right eye would lean to the right, and the one seen by the left eye would incline to the left. It appears that each oblique muscle is connected by individual nerve fibers with three centers—one center, basal; the two others, probably cortical. The former center has connected with it fibers from only one muscle, but each of the latter has connected with it fibers from two oblique muscles, one of these belonging to one eye and the other to the other eye; and, therefore, they are conjugate centers. All the fibers from these three centers come together and form the trunk of the nerve, a disease of

which suspends the independent and conjugate action of the muscle supplied by it; and the muscles of the fellow eye are not involved. The right superior oblique is connected with the sixth conjugate center, as is also the left superior oblique; the right superior oblique is also connected with the eighth conjugate center, as is also the left inferior oblique. Disease of the sixth center, as already shown, gives trouble only when looking directly down; disease of the eighth center causes trouble, as shown above, only when looking up and to the right, or down and to the left. Disease of these two conjugate centers would have no influence over the basal center that gives duction or fusion power to either of the two muscles mentioned—that power that is exercised when images are displaced by oblique astigmatism, natural or artificial.

Each rectus muscle is also connected with three centers—one center, basal; the two others, cortical. The former is reflex; the latter, volitional. To illustrate: The right internus has its reflex center—the center giving it duction or fusion power—in the nucleus of the mortor oculi; it is also connected with the third conjugate brain-center, as is also the left internus; it is also connected with the fifth conjugate center, as is also the left externus. All the fibers from these three centers for the right internus form the bundle that constitutes the branch of

the third nerve, supplying it with its threefold power. Disease of this branch suspends both the reflex (fusion) and voluntary power of this muscle; it can neither adduct, converge, nor advert the eye to which it belongs. Disease of the third conjugate center involves only those fibers that convey to the muscle the convergence impulse; disease of the fifth conjugate center involves only those fibers that convey the adversion impulse; likewise disease of the reflex nucleolus involves only those fibers that convey the fusion impulse. Disease of the third conjugate center would suspend, of course, the converging power of the left internus also; while disease of the fifth conjugate center would affect the abverting power of the left externus as well as the adverting power of the right internus. Thus each muscle, with its several centers, might be studied.

It only remains to speak of the symptoms that would present themselves, should any one of the five conjugate centers, controlling the recti, become diseased:

(1) Disease of the first conjugate center: inability to supervert the eyes, but no diplopia.

(2) Disease of the second conjugate center: inability to sub-vert the eyes, but no diplopia.

(3) Disease of the third conjugate center: inability to converge the eyes, with diplopia in the near.

(4) Disease of the fourth conjugate center: inability to rotate the eyes to the right, either cardinally or obliquely, but no diplopia.

(5) Disease of the fifth conjugate center: inability to rotate the eyes to the left, either cardinally or obliquely, but no diplopia.

Treatment.

In any form of paralysis of muscle—that is, when the disease causing it is below the internal capsule—the diplopia should be prevented by covering the affected eye, which will relieve all nervous symptoms, such as headache, dizziness, and nausea. The affected eye should be kept under cover until the disease has been cured. In paralysis of the third nerve, nature supplies the cover in the production of ptosis, and usually the last muscle, supplied by the third nerve, to regain its power is the elevator of the upper lid. If any case is clearly rheumatic, it should be treated with large doses of the salicylate of sodium or other anti-rheumatic remedy; if the cause is syphilis, iodide of potassium in increasingly large doses should be given after meals; if the cause is not known, the case should be treated with the iodide of potassium. Early in any case the administration of the fluid extract of jaborandi, in doses of twenty drops at 9 A.M., 3 P.M., and 9 P.M., by pro-

moting absorption of effused serum, will greatly aid the iodides in the work of hastening the absorption of plastic effusion. Bichloride of mercury in small doses may also be given.

The above remedies should be continued until the diplopia has entirely disappeared. This much having been accomplished, the sulphate of strychnia in doses of $\frac{1}{100}$ to $\frac{1}{50}$ of a grain should be given before each meal. At this stage the interrupted current of electricity, used once daily for ten minutes, will do good. While there is still diplopia, the strychnia and electricity would do harm, rather than good.

In old cases of ocular paralysis, when there can be no longer any hope of restoration of power to the paralyzed muscle, surgery will do good, in that it will lessen the field of diplopia and give to the patient a more natural pose of the head. The operation should be either an extensive shortening or advancement of the paralyzed muscle, and never even a partial tenotomy of the antagonist. The muscle plane should be changed or not, when making the shortening or advancement, as may be indicated by the existence or non-existence of torsion.

LAGOPHTHALMOS.

The condition termed "lagophthalmos" was so named because it gave to the human eye the appearance of the eye of the hare—always open, asleep or awake. The cause of the condition is disease of the seventh nerve in its course; or at its basal or cortical centers, or between these two—in the internal capsule or in the corona striata. In either case there is a greater or less loss of power on the part of the corresponding orbicularis, and usually the muscles of the face are also involved. The location of the disease or injury determines the array of symptoms to be presented in any case.

When the part involved is the basal center of the nerve, or the body of the nerve as it finds its way out to be finally distributed to all the muscles of the face, including the orbicularis of the corresponding side, all these muscles will be paralyzed, and the logaphthalmos will be only one of the symptoms. The skin of the forehead on the affected side is smooth, as if "ironed out," and the patient is wholly unable to throw it into wrinkles for the reason that this half of the anterior part of the occipito-frontalis is supplied by the diseased nerve; the corrugator supercilii must also be inactive, therefore the brow on that side cannot be drawn down; the various muscles connected with the nose and mouth, action of which goes so far to give agreeableness of expression to

the face, cannot receive a nerve impulse, therefore they must be inactive, and the face, on that side, becomes expressionless; the buccinator, which is also supplied by the seventh nerve, loses its power and thus the mastication of food on that side becomes inconvenient—almost impossible—for the reason that, when the tongue presses the food between the teeth, the buccinator being unable to make counter pressure, the food cannot be kept between the grinders. Soon the patient learns to do all his chewing on the unaffected side. The mouth is always drawn toward the unaffected side, and a laugh will be confined wholly to this side. The patient drinks with difficulty and cannot whistle. All of these symptoms will be associated with the inability to close the eye.

Both parts—the voluntary and the involuntary—of the orbicularis being involved, the eye will be wide open, and there will be no power to close it. Any great effort to close it will only cause the eye to move upward, as if to hide behind the upraised lid. The lower lid will not be held in contact with the globe, hence the punctum will be displaced. The absence of the batting power makes it impossible for the punctum of the upper lid to carry off the tears; hence there must be an excess of tears in the conjunctival sac. The unprotected eye becomes irritable, as shown by conjunctival redness, ex-

cessive secretion of tears, and some dread of light. If the eye is exposed too long and too severely, the cornea may ulcerate, when the eye, of course, becomes painful.

By far the most common cause of lagophthalmos, associated with the other symptoms already described, is inflammation of the middle ear, and the reason is not hard to find. The seventh nerve, as it passes through the aqueduct of Fallopius, in the inner bony wall of the drum cavity, should be completely covered in by bone structure. That this bone-covering is complete, in many cases, is made evident by the fact that otitis media is not attended by involvement of the seventh nerve; that it is incomplete, in some cases, is made equally evident because of the fact that in some cases even a very slight otitis media is attended by paralysis of all the muscles of the face. Whenever there is a break in the bony covering, the mucous membrane lining the inner wall of the drum cavity must lie directly in contact with the sheath of the seventh nerve, hence the readiness with which an inflammation of this membrane may involve the nerve. Catarrhal, as well as suppurative, inflammation of the middle ear, in such cases, almost always causes facial paralysis. When such is the cause of facial paralysis, the usual symptoms of inflammation of the ear are present—namely: pain, fullness, and deafness, with some fever. The objective symptoms are

also present. If the inflammation causing the paralysis is between the basal center of the seventh nerve and the point where the eighth nerve parts company with the facial nerve, to find its terminals in the internal ear, the resulting pressure will cause deafness, as well as paralysis of the facial muscles; but other symptoms and signs of otitis media will be absent. In the latter case the paralysis of the orbicularis will be as complete as in the former. If the inflammation or injury of the facial nerve is at some point between where it leaves the aqueduct of Fallopius and the point where it divides into its several branches, the facial paralysis will be complete; but the hearing will not be involved, nor will there be any other symptoms referable to the ear. In all of these conditions the batting power is lost.

When the cause of the lagophthalmos is in the cortex, the lids are not so widely separated, and their batting power, though modified, is not lost. The other muscles of the face may not be involved. If the disease in the cortex, in the internal capsule, or in the corona radiata is extensive, other symptoms will be found in association with the lagophthalmos. Such cases are not so likely to recover full voluntary power over the orbicularis.

Treatment.

Whatever may be the cause, the eye should be protected by a flap until such time as the lids may have

recovered their power; otherwise, the cornea may ulcerate. If otitis media is the cause, this condition should be so treated as to prevent suppuration, if possible; but if suppuration occurs, the disease should be so treated as to bring it, as speedily as possible, under control. In all cases the iodide of potassium and the bichloride of mercury should be administered for promoting absorption of inflammatory deposits within the sheath of the nerve. In this work these drugs can be greatly aided by the fluid extract of jaborandi, in twenty-drop doses, three times a day for the first two weeks. Strychnia should be given only when a return of voluntary power to the facial muscles shows that the pressure of inflammatory deposits has been relieved more or less completely. When the cause of lagophthalmos is above the basal, or reflex, center, sorbefacient treatment is indicated; but, as already stated, recovery is both slow and doubtful.

CHAPTER XII.

MUSCLES OF THE IRIS AND OF THE CILIARY BODY.

THE heading of this chapter is intended to convey the idea that the iris has more than one muscle, and that in the ciliary body there is more than one muscle. Both anatomy and physiology give evidence of the existence of two muscles in the iris; anatomy shows two sets of muscular fibers in the ciliary body, and there is also physiologic evidence of the existence of two independent muscles, each under a separate innervation.

MUSCLES OF THE IRIS.

At one time in the history of medicine it was taught that there was erectile tissue in the iris which, by becoming filled with blood, would make the pupil small, and, by again becoming empty, would effect the dilatation of the pupil. Other theories were offered from time to time, accounting for the changeableness of the pupillary opening in the iris, without taking into account the necessity for muscular contraction to effect these

changes. As early as the tenth century an Arabian physician announced his belief in the existence of muscles in the iris, contractions of which varied the size of the pupil, his only evidence being physiologic. In his day there were no means of investigation to determine anatomically the existence of muscle structure so small. Descartes, though neither an anatomist nor a physiologist, announced in one of his publications, in the seventeenth century, that muscles in the iris regulated the pupillary opening.

The existence of radiating fibers was generally conceded a long time before Berger announced, in 1701, that orbicular fibers also existed in the iris. It was not until 1812 that the microscope, under the eye of Maunoir, revealed the existence of circular fibers in the iris of the bird. From that time to the present there has been no one ready to deny the existence of the circular muscle of the iris. The microscope has since demonstrated the existence of the sphincter muscle of the iris in man. It is known to be a circular muscle-band, about one millimeter wide, at the pupillary margin of the iris and nearer its posterior surface.

Radiating muscular fibers in the iris has been a matter of much discussion, but now the preponderance of evidence is in favor of the existence of such fibers. Grunhagen, Collins, and others have taught that there is

elastic tissue in the iris that effects the dilatation of the pupil whenever action of the sphincter is inhibited—that the dilatation is effected passively, and not actively. Juler, at the eighth International Congress of Ophthalmology, in 1894, announced that, by a new method of investigation, he had been able to show, under the microscope, the radiating muscular structure of the iris. This anatomic evidence, associated with the evidence given by physiology, removes the question of the existence of a pupil-dilator muscle entirely from the domain of doubt. Juler has demonstrated that the radiating muscular fibers have their origin at the attached margin of the iris, and pass to the pupillary margin, where they become blended with the sphincter muscle.

Petit observed, in 1727, that a division of the cervical sympathetic caused contraction of the pupil; and Biffi, in 1846, showed that stimulation of the cervical sympathetic effected dilatation of the pupil. By a similar method of investigation, Mayo, in 1823, proved that the sphincter muscle of the iris is supplied by the third cranial nerve, a division of which dilates the pupil, while stimulation of this nerve makes the pupil contract.

There is no room for doubting the existence of these two muscles in the iris; and that they are antagonistic—the one contracting the pupil, the other effecting its dilatation—is as little open to doubt.

Those fibers of the third nerve and of the cervical sympathetic, that give power, respectively, to the pupil-contractor muscle and the pupil-dilator muscle, pass first to the ciliary ganglion, in which they are joined by fibers from the fifth nerve. From this ganglion the several short ciliary nerves, each containing fibers from the three different sources, make their way to the posterior part of the eye, which they enter. They are finally distributed to the ciliary body and the iris, giving sensation to these structures and power to their muscular parts.

The function of the iris is to regulate the quantity of light that enters the eye, and this it does reflexly. A too-bright light makes it necessary for the pupil to be made smaller, which is effected by an impulse sent from the nucleolus of the third nerve-center that controls the sphincter of the iris; a dim light takes the nucleolus of the sphincter off its guard and allows the influence of the cervical sympathetic on the radiating fibers of the iris to effect the dilatation of the pupil. There should be harmony in the antagonism of these two muscles, for the purpose of properly regulating the quantity of the light that enters the eye. The iris also serves to cut off the peripheral rays of every cone of light, which enables the refractive media to make a focus sharper than it would be if spherical aberration were not thus prevented.

In most cases the muscles of the iris do their work well. There are cases, however, in which either the sphincter muscle is too weak, because of poor development or slight innervation, or the pupil-dilator muscle is abnormally strong from hyper-development or over-stimulation; as a result, the pupil is too large under ordinary light and when shaded. Under the stimulus of strong light it contracts; but if such exposure is prolonged, the contraction of the sphincter becomes painful. Any one of several symptoms of eye-strain may be caused by prolonged contraction of a weak sphincter of the iris. Such patients cannot endure, with any comfort, prolonged exposure to bright light, whether natural or artificial. The author has observed a fairly large number of such cases, and has had a fair degree of success in managing them. A weak pupil-dilator muscle is not likely to be the source of annoying symptoms. A patient with weak pupil contractors should have these muscles treated, regardless of what else must be done for the relief of other conditions that may cause strain.

Treatment.

Patients with large pupils, who suffer when exposed to bright light, may have their pupil contractors developed and strengthened by exercise. The method is as follows: Before retiring at night, the patient should

sit before a fairly bright lamp, holding in one hand a densely opaque cardboard which she should place between her and the light at regular intervals of two or three seconds, looking all the time in the direction of the light. Thus there would be alternate exposure of the eyes to light and darkness, producing rhythmic contraction and relaxation of the sphincter of the iris. For this exercise ten minutes will be sufficient; but should the eyes become fatigued, the exercise should cease sooner. The exercise should be repeated every night for a long while.

In the absence of the exercise treatment, the only thing to be advised is the wearing of smoke lenses constantly, or whenever the eyes are to be exposed to bright light. These lenses allow the pupils to become more or less enlarged, which means that the sphincters are thereby rested. This method favors the muscle in its weakness, and is not to be preferred to the exercise treatment, for the latter means that the sphincter will be made strong eventually.

Muscles of the Ciliary Body.

It was not known until 1846 that there were any muscular fibers in the ciliary body; but at this time Bowman discovered, with the microscope, muscular fibers which were parallel with the meridians of the eye, hence properly called them "meridional." These he considered as

having their origin in the anterior part of the ciliary body and their insertion in the anterior part of the choroid. He named this newly discovered muscle the "tensor of the choroid," and in it he thought he had found the secret of the power of accommodation. His explanation was that this muscle, by making tense the choroid, so compressed and changed the shape of the vitreous as to force the lens forward, thereby increasing the distance between the macula and the lens sufficiently, he thought, to account for the phenomena of accommodation. Before that time no theory of accommodation had included the idea that there existed, in the ciliary body, a muscle. So thoroughly satisfied was Bowman that he did not pursue his investigations further, else he would have discovered, also, the circular fibers which were discovered later by H. Müller. Long before the discovery of either Bowman's muscle or Müller's muscle (that there are two muscles will be shown farther on), Young had demonstrated an increase in the curvature of the crystalline lens in the act of accommodation. Müller thought that, by contraction of the circular muscle discovered by himself, direct pressure, by the ciliary processes, on the periphery of the lens, caused the increase in convexity; but Helmholtz had taught that the increase in curvature was due to inherent elasticity of the lens, which was allowed to manifest itself because of

relaxation of the zonula, effected by the contraction of Bowman's muscle.

It would seem that all authors are agreed that in the ciliary body there are two sets of muscular fibers—one set running parallel with the meridians, and another collection of fibers forming a circle in the anterior part of the ciliary body. There is universal agreement, also, that one or the other of these muscles, or both, is the active agent in accommodation. It is also universally conceded that the accommodative muscle is supplied by the third nerve.

The microscope has revealed the fact that there are two muscles—or, at least, two different arrangements of muscular fibers—in the ciliary body; the existence of two independent muscles, each getting its nerve supply from a separate source, appears to be shown by physiology. Young, in 1801, demonstrated increased curvature of the lens in accommodation; Helmholtz accounted for this in relaxation of the zonula by a contraction of the muscle of Bowman—the so-called "tensor of the choroid"—when he could have accounted for it more easily in a contraction of the muscle of Müller, which, by making more narrow the zone between the ciliary processes and the periphery of the lens, necessarily relaxed the suspensory ligament of the lens, thus allowing the lens to manifest its elasticity. By becoming more convex, the lens would

necessarily take up the laxness of the ligament. A fact strongly favoring the idea that the muscle of accommodation is Müller's muscle is that Coccius has seen, in eyes on which an iridectomy had been done, a narrowing of the circumlental zone in the act of accommodation. It is easier to understand how the circular muscle (Müller's) could relax the zonula, and thus enable the lens to become more convex, than it is to understand how Bowman's muscle could effect the same changes. In fact, it would appear that, if Bowman's muscle is the active agent in accommodation, the zonula would be made more tense, and would, therefore, prevent the lens from increasing in convexity; but, on the contrary, the lens would be compressed toward its periphery. If Bowman's muscle is the active agent in accommodation, it is supplied by the third, or mortor oculi, nerve, and the change of the lens would be more in position than in curvature; the change in curvature would not be an increase in spherical curvature, but it would be the formation of a lenticonus. There, then, could be no possible use for the circular muscle of Müller. If the Müller muscle is the active agent in accommodation, it is supplied by the third, or mortor oculi, nerve, and the change in the lens would not be in position, but wholly in curvature; the change in curvature would be in an increase of the sphericity of the lens—a shortening of the radius

of the anterior curve—made possible by a narrowing of the circumlental zone. If this is the work of the Müller muscle, there would still remain a work to be done by the Bowman muscle, which will be set forth farther on.

The answer to the question, "Is the muscle of Bowman or the muscle of Müller the active agent in accommodation?" must come from a study of the actual change that occurs in the lens in the accommodative act. If Bowman's muscle is the muscle of accommodation, Tscherning's views as to the condition of the zonula and the state of the lens in accommodation must be correct—that is, the zonula must be on the stretch, and the anterior surface of the lens must assume the shape to which he has given the name "lenticonus." If in accommodation the zonula is relaxed, a more rapid spherical curvature of the lens is possible, and these changes can be effected only by the contraction of Müller's muscle. Helmholtz would be correct, at least in part; he would be wrong only in the thought that the narrowing of the circumlental zone had been effected by Bowman's muscle.

Is the change in the lens the formation of a lenticonus, according to Tscherning, or is it an increase in the curvature of the anterior surface, according to Young, Helmholtz, Donders, and many others? One thing should be conceded at the outset—that is, there is in accommodation a narrowing of the circumlental zone, the space

between the ciliary processes and the periphery or equator of the lens. All writers agree that in the absence of accommodation the two surfaces of the lens are spherical. Now, suppose the eye of one individual to be emmetropic, and the eye of another person to be hyperopic. The emmetropic eye, without any accommodative effort, has vision equal $\frac{20}{XX}$, and that through a lens whose surface must be conceded to be spherical. The person with the hyperopic eye (say of 3. D), by the aid of his accommodative power, also has vision equal $\frac{20}{XX}$. Surfaces differently curved cannot refract light in the same way. If the emmetropic eye saw through a lens having a spherically curved surface, the hyperopic eye, in the act of accommodation for distant seeing, must have had also a lens whose surface was spherically curved. If accommodation of 3. D for distant seeing does not produce a lenticonus, is it possible that accommodation of 3. D for near seeing will do so? Again, suppose one person to be emmetropic and sixty years old, but still possessing a perfectly transparent lens; and suppose another person emmetropic and sixteen years old. These two persons will have equally good distant vision, without any accommodative effort on the part of either. At a distance of thirteen inches the older person, not having any accommodative power, cannot see to read; while the younger person, by the exercise of accommodation, sees every

word and letter perfectly. On placing a plus 3. D lens before the eye of the older person, everything on the page becomes as clear and as distinct to him as it is to the younger person. The lens of the older person has not lost its sphericity in changing the point of view from twenty feet to thirteen inches, for he has no accommodative power; but for him the plus 3. D *spherical* lens has made divergent rays parallel, and these parallel rays are easily and accurately focused on his retina by his own spherically curved crystalline lens. If the two spherically curved bodies—the presbyopic lens and his crystalline lens—have made the old man see perfectly, has it been necessary for the surface of the crystalline lens in the young person to become changed to a lenticonus in order that he might see distinctly at thirteen inches? Either the surface of the crystalline lens in the young person has not changed from a spherical curve, when there was no accommodation, to a lenticonus, in accommodation, or a presbyopic lens should be a lenticonus, and not spherical. In conclusion, this statement will be made without fear of contradiction: Spherical refractive surfaces, with the peripheral rays cut off by a perforated diaphragm, can reproduce perfectly, point for point, an image of the object from which the rays of light have come.

For the reasons given above, the logical conclusion is

that in accommodation the zonula is relaxed by a narrowing of the circumlental zone, that this laxness is taken up by an increase in the convexity of the elastic crystalline lens, and that these changes can be effected only by a contraction of Müller's muscle. Since Müller's muscle is the active agent in accommodation, it is supplied by the third nerve.

Since Tscherning published his views concerning accommodation, it has been demonstrated by Hess that the zonula is relaxed in accommodation; and Priestly Smith has claimed that it is possible for the anterior surface of the lens to assume the lenticonus shape, in accommodation, when the zonula is relaxed.

As already stated, there is a use for the muscle of Bowman, regardless of the fact that it is not the active agent in accommodation. There is a reason for believing that this muscle, like the radiating muscle of the iris, is supplied by the cervical sympathetic, through the medium of the ciliary ganglion. It is generally taught that at least some of the meridional fibers extend from the anterior part of the choroid through the ciliary body, terminating in the part occupied by the circular muscle (Müller's) in the region of the attachment of the zonula to the ciliary processes. They pursue such a course and are so related to the suspensory ligament that it appears highly probable that it is through the active agency of

these fibers (Bowman's muscle) that the crystalline lens is made to assume a mathematically correct position in its bed in the anterior part of the vitreous. This normal and mathematically correct position—the position that it must occupy when there is no corneal astigmatism—is such that the antero-posterior axis shall coincide with the visual axis, and that its equatorial plane shall be parallel with the equator of the eye. In the process of development the lens, in many instances, may passively assume the proper position; and, if so, there would be nothing for Bowman's muscle to do; but in many instances the passive position assumed by this lens in its development would not be mathematically correct, hence the need of some active agent for readjusting. This agent could be, and doubtless is, Bowman's muscle, and the medium through which this muscle could effect the readjustment is the suspensory ligament—the zonula. The agent calling on Bowman's muscle to do this work would be the guiding sensation of the retina, which is the taskmaster of all the ocular muscles, intrinsic and extrinsic. The time for effecting this readjustment would be after birth, for before birth the guiding sensation must be dormant. The task of readjustment is, doubtless, fully accomplished in infancy, or, at the latest, early in childhood. It is not more wonderful that Bowman's muscle should be endowed with this unvolitional

power than it is that Müller's muscle, likewise under the control of the guiding sensation, should be endowed with power to mathematically adjust vision for all distances.

If Bowman's muscle can readjust the lens in an eye whose cornea is free from astigmatism, so that its position shall be mathematically correct, is it not also possible that the same muscle may be the active agent in producing a lenticular astigmatism at right angles to a corneal astigmatism for the purpose of neutralizing it? Suppose a case of corneal astigmatism of 2. D, with the meridian of greatest curvature at one hundred and eighty degrees; to correct this by a neutralizing lenticular astigmatism, an impulse would have to be sent to a collection of meridional fibers, either directly above or below the lens, a contraction of which would tilt the lens on its horizontal axis so as to increase the refractive power of its vertical meridian to the extent of 2. D. Thus would the corneal astigmatism be neutralized. It is well known that the tilting of a lens increases its refractive power at right angles to the axis of tilting. Tilting a lens forty-five degrees practically doubles its strength at right angles to the axis of rotation, without changing its power in line with this axis; and in this way a spherical lens is made to have an astigmatic effect. The strength of the crystalline lens is so great that a very slight tilting

would produce a considerable astigmatic effect. Lenticular astigmatism cannot be effected by a contraction of Müller's muscle, but it can be easily effected by the action of individual fibers of Bowman's muscle. How the guiding sensation can select and call into action a few fibers of Bowman's muscle, yet allow all the balance of this muscle to remain quiet, is not subject to explanation.

The author does not have to suppose a case of corneal astigmatism that, in some way or other, was neutralized automatically, to a considerable extent, for many years. His own corneal astigmatism is 2.50 D, and has been so since 1889, when Swan M. Burnett, of Washington, measured it with Javal's ophthalmometer. The first attempt at astigmatic correction by artificial means was made in 1882, under the influence of atropine. The correcting cylinder for each eye was plus .65. In 1885, again under a mydriatic, L. Webster Fox, of Philadelphia, found the correcting cylinder for each eye to be plus .75. In 1887 a plus 1. cylinder for each eye was given. Again, in 1888, a plus 1.25 cylinder for each eye fully corrected the manifest astigmatism, a mydriatic again being used—this time, homatropine, gr. viii. to water oz. i. Ten drops, one every five minutes, were placed in each eye, and at the end of half an hour the examination was made. From that time until 1895 more astigmatism became

manifest, but the stronger cylinder was not given until that date. The cylinder then given was plus 2. D for each eye. In 1900 the cylinder given for the right eye was plus 2.25, and that given the left eye was plus 2.50—practically a full correction of the corneal astigmatism, which during at least eleven years had remained the same, as shown by the Javal ophthalmometer.

The author has thus related his own experience for the purpose of giving emphasis to two points: (1) There was a lenticular astigmatism that almost completely neutralized the corneal astigmatism up to the age of twenty-eight years; (2) the power that effected the neutralizing lenticular astigmatism was not suspended by the repeated use of mydriatics, and this power, therefore, could not have been given through the fibers of the third nerve that come from the ciliary ganglion. The logical conclusion is that the lenticular astigmatism was produced by fibers of Bowman's muscle, and that these fibers derived their power from the cervical sympathetic.

A personal experience, similar to that through which the author has passed, has been related by Edward Jackson, of Denver. What Jackson's explanation is, the author does not know. Doubtless many others have had a similar personal experience; and it is not too much to say that every observer has had such cases in his practice. Occasionally men of large experience have seen

cases of astigmatism to be accounted for only by an astigmatic condition of the crystalline lens.

It may be that, in some cases, a much higher degree than 2.50 D of corneal astigmatism could be neutralized by a lenticular astigmatism. It is true, nevertheless, that, in many cases, even a low degree of astigmatism is not always thus neutralized, the Bowman muscle being unable, from some cause, to effect the necessary change in the lens.

If a tilting of the lens by contraction of a single part of Bowman's muscle is not the cause of the lenticular astigmatism, the simultaneous and equal action of two opposite parts of Bowman's muscle, by making tense the corresponding parts of the zonula, could so compress the part of the lens intervening as to increase its refractive power, thus effecting lenticular astigmatism. It would appear that, in one of these two ways, the muscle of Bowman causes a neutralizing lenticular astigmatism. If this change is caused by a tilting of the lens, it is reasonable to suppose that the work of tilting could be transferred from one part of the muscle to another part directly opposite. For instance, in the production of a lenticular astigmatism for neutralizing a corneal astigmatism—meridian of greatest curvature, vertical—the lens could be tilted on its vertical axis by contraction of either the nasal or the temporal part of Bowman's mus-

cle; for the effect would be the same, whether the nasal part of the lens is thrown forward by contraction of the temporal part of the muscle, or thrown backward by a contraction of the nasal part of the muscle. Both of these parts would have to contract simultaneously and equally if the lenticular astigmatism is a result of change in curvature, and not a change in position. In either instance, the work done would be strain, and possibly one of the worst forms of eye-strain.

After the foregoing study of the muscles located in the ciliary body, this chapter may be concluded with a study of the normal work required of each in some conditions of refraction, and the abnormal work required of them in other states of refraction.

THE FUNCTION OF THE MÜLLER MUSCLE.—No muscle of the eye is ever called on to do either normal or abnormal work for any other purpose than the improvement of vision, and these calls are always made by the guiding sensation, which resides in the macula, or, at the farthest, within the retinal area of binocular fusion. The contraction of Müller's muscle is intended only to increase the refractive power of the crystalline lens equally in all of its meridians. This change in the refractive power of the lens is effected by two agents, Müller's muscle being the active agent and the elasticity of the lens being the passive agent. When the Müller

muscle is at rest, the zonula is tense, and, by its pressure against the lens, suspends the elasticity of the latter, in which state it has its minimum power of refraction. When the guiding sensation calls for a sharper image on the macula, the response comes in an impulse sent through those fibers of the third nerve that end in the muscle of accommodation (Müller's). At once this muscle contracts equally in its entire extent, relaxing the zonula, the laxness of which is at once taken up by an increase in the convexity of the lens by its own elasticity. The degree of contraction of the muscle is regulated with mathematical precision, and the change in refractive power of the lens is only enough to satisfy the guiding sensation.

Emmetropia.—In this condition of refraction, Müller's muscle is never called into action when the object looked at is in the distance; but when the point of fixation is at thirteen inches, in response to a demand from the guiding sensation, an impulse is sent to this muscle sufficiently powerful to effect a contraction that will increase the refraction of the crystalline lens by 3. D. At nine inches a 4. D impulse must be sent to the muscle; but when the point of fixation is at the distance of 1 M, only a 1. D impulse is needed. Looking again into practical infinity—any distance beyond twenty feet—the Müller muscle goes into a state of rest, to be aroused

into activity again only when the point of view is near by. In distant seeing, not only is the muscle of accommodation at rest, but all of the recti; and the obliques should also be in a state of rest, and they will be in this state if there is orthophoria. As shown elsewhere, the brain-center controlling the ciliary muscle (Müller's) is in some way associated with the third conjugate center (convergence center), so that for every dioptre of accommodation there is a convergence of each visual axis of nearly two degrees of arc, which would mean about four degrees of prism—a point not made clear in the study of pseudo-esophoria.

In emmetropia and orthophoria everything is favorable for comfort in the use of the eyes. Such eyes, under ordinary use, can give trouble only when in the emmetropic eye there is a weak muscle of accommodation or when the orthophoria is asthenic. What should be done for the asthenic orthophoria has already been set forth; what should be done to strengthen a weak muscle of accommodation will be shown farther on in this chapter.

In a normal condition, the strength of Müller's muscle varies with the age of the patient, until advancing years deprive it of all power. The table showing the variation in strength, as given by Jackson, is probably as nearly correct as any. The error, if any, is in the showing of too much ciliary power after the age of thirty

years. This table shows the relative or associated accommodation, and is much greater than would be shown if accommodation, unassociated with convergence, were tested with concave lenses. Jackson's table is as follows:

Age.	Accommodation in Dioptres.	Distance of Point of Fixation—Inches.
10	14.	2.81
15	12.	3.28
20	10.	3.94
25	9.	4.4
30	8.	4.9
35	7.	5.6
40	5.5	7.1
45	4.	9.84
50	2.5	15.75
55	1.25	31.5
60	.5	75.74
65	.0	.00

The above table shows that the amplitude of accommodation, which is the distance between the far and the near points, grows less with advancing years, until, at the age of sixty-five years, the near point has receded so far that it becomes one with the far point.

The recession of the near point is due either to an actual weakening of Müller's muscle or to a gradual loss of elasticity of the lens, probably both. If the muscle could be kept strong, the elasticity of the lens would doubtless

be maintained longer. The method for keeping the ciliary muscle strong will be set forth in answer to the question: "Can presbyopia be deferred?"

HYPEROPIA AND HYPEROPIC ASTIGMATISM.—In either of these conditions of refraction the guiding sensation will call for activity of Müller's muscle in both distant and near seeing. In hyperopia the accommodation, unassociated with convergence, must effect just such an increase of the refractive power of the lens, for distant vision, as will render sharp the image of the object of fixation. This necessity for the exercise of the accommodation for distant seeing disturbs the harmony between accommodation and convergence. For every dioptre of accommodation for distance there is developed nearly two degrees (of arc) of pseudo-esophoria, which would be measured by a prism of nearly four degrees. In the discussion of pseudo-esophoria this distinction between arc and prism degrees was not made; hence the author would emphasize it here. Wherever the quantity of pseudo-esophoria is given in the chapter on esophoria, it should be read "of arc," or it should be multiplied by two to read "of prism."

In manifest hyperopic astigmatism, simple or compound, the guiding sensation must be satisfied when Müller's muscle has so accommodated as to place the focal interval on the macula, for vision of astigmatics is

best for all parts of an object when the anterior focus is just as far in front of the retina as the posterior focus is behind it. This is shown in the half-tone cut on page 340. However, the muscle can accommodate so as to place either the anterior or the posterior focus on the macula—in the first instance, sharpening lines at right angles to the meridian that is most curved; in the second instance, sharpening lines that are parallel with the most curved meridian. This irregular, zigzag contraction of Müller's muscle is what occurs when hyperopic astigmatic eyes look at checked goods—a very unpleasant thing for them to do.

This work of Müller's muscle—to sharpen images in hyperopia and hyperopic astigmatism—is abnormal, and always develops a pseudo-esophoria. The pseudo-esophoria manifests itself in one of three ways: First, it shows an esophoria, when, intrinsically, there is orthophoria; second, it shows a greater amount of esophoria than really exists; third, it lessens an existing intrinsic exophoria. In either instance, if the muscle of accommodation is not of subnormal development, the pseudo-esophoria will be the same in both far and near vision.

In any case of hyperopia or hyperopic astigmatism, the error must be considered—not wholly with reference to the muscle of Müller, but the inherent condition of the lateral recti muscles must also be taken into consid-

eration. If there is lateral orthophoria, and especially so if there is an inherent esophoria, the abnormal work required of the muscles of accommodation should be relieved by a full correction of the focal error, and the lenses should be worn for both far and near seeing. If there is inherent exophoria, it would be better, in many cases, especially those having strong muscles of accommodation, to correct the hyperopic astigmatism with minus cylinders, and to leave uncorrected any low degree of hyperopia, in order that the pseudo-esophoria may neutralize, wholly or in part, the inherent exophoria. In every case of hyperopic astigmatism a full correction of all the error that can be made manifest should be given, using either plus or minus cylinders, as might be indicated by an associated study of the focal error and the intrinsic state of the muscles. If minus cylinders are used because of a complicating exophoria, the hyperopic astigmatism, which is worse, is converted into a simple hyperopia, which is better. How to deal directly with any inherent muscle imbalance, has already been set forth in preceding chapters.

MYOPIA AND MYOPIC ASTIGMATISM.—When either of these errors exists, the guiding sensation does not call on Müller's muscle to do any work when the object of fixation is in the distance. If there is simple myopia of 3. D, or more, the muscle of accommodation is not called

into action, even in the near use of the eyes; so that in such eyes the muscle remains inactive, whatever may be the location of the point of view, unless it should be brought nearer the eyes than their far points. If there is manifest myopic astigmatism, the accommodative muscle will be brought into activity only when the eyes are used in near vision and for the purpose of placing the focal interval on the macula. In compound myopic astigmatism, the myopia being 3. D or more, the muscle of Müller will remain inactive, regardless of whether the eyes are being used either in the far or in the near. In myopia of less than 3. D, with the page at thirteen inches, the guiding sensation calls only for such accommodative action as will increase the refractive power of the lens to correspond, in dioptres, with the difference between the number of dioptres of myopia and 3. D. This work of the ciliary muscle—to improve vision in the near when there is myopic astigmatism, and to give the proper near point when there is a low degree of myopia—is abnormal work, though less than is required when there is emmetropia. These refractive errors interfere in no way with any intrinsic muscle condition, when the point of view is in the distance; but in the near use of the eyes there is a resultant pseudo-exophoria. This may show itself in any one of three ways: First, there will be an exophoria in the near, when, intrinsically, the lateral muscles may

be well balanced; second, the manifest exophoria will be more than the real; third, the pseudo-exophoria may serve to lessen an inherent esophoria.

In any case, a full correction of a myopic error for the purpose of distant seeing should be given, since such a correction will not excite into activity the muscle of accommodation, nor will it interfere with any existing state of the lateral muscles. There can arise no disadvantage from wearing the correcting lenses for distant vision, and there is a very great source of pleasure given in making sharp and well defined objects that are remote. When the associated muscle condition is inherent orthophoria, and especially when there is exophoria in the near, myopes should wear their correcting lenses for both far and near seeing; but when there is esophoria, as will be shown in both the distant and the near tests, the myope will have added comfort by removing his lenses for all near work, in that the pseudo-exophoria will lessen the intrinsic esophoria. In all cases, myopic astigmatism should be corrected by a proper minus cylinder when there is lateral orthophoria or exophoria in the near, but by plus cylinders, to be worn only in reading or in other near work, when there is a complicating esophoria. So it appears that myopic errors must be studied and treated by taking into consideration the Müller muscle and the lateral recti muscles.

WEAKNESS OF MÜLLER'S MUSCLE.—As already shown, the amplitude of accommodation diminishes with advancing years. Whether this failing accommodation is due to loss of power in the muscle, or whether it is because the lens, growing more dense, continually suffers loss of elasticity, is still a subject for discussion. Probably the two conditions enter as factors in the development of presbyopia. The weakening of the muscle of accommodation may favor the loss of elasticity, and the loss of elasticity may react on the weak muscle. Presbyopia shows itself in a recession of the near point until, finally, it has been removed inconveniently far. Before this, however, the muscle may have become so weak that its use in reading or other near work brings on fatigue, headache, or other symptoms of eye-strain. In such cases one of two things should be done: The muscle should be helped by increasing its strength by exercise, or by supplementing its power.

Can presbyopia be deferred? What the author wrote in 1894, in answer to this question, so perfectly coincides with his present views, that he reproduces it here:

"That the leading cause of old sight is failure of ciliary power we think may be proved; and if this is true, simple and scientific means for deferring the onset of presbyopia may be brought into use. Rhythmic exercise can be as readily effected in the ciliary muscle as in

any of the extra-ocular muscles. Will this exercise develop the power of these muscles that are under the direct control of the *guiding sensation*, the common master of all the ocular muscles?

"That involuntary muscular fibers can be increased in size and augmented in power as a result of effort to overcome obstruction is a matter of common acceptance, so far as the heart and the bladder are concerned. In mitral stenosis it is well known that the walls of the left auricle become hypertrophied and more powerful, so that it may send the blood through the narrowed opening into the ventricle; in like manner, when there is obstruction at the aortic opening, the walls of the ventricle become hypertrophied and more powerful.

"When the prostate gland is enlarged or there is stricture of the urethra, impeding the flow of urine, the muscular fibers in the walls of the bladder are increased in size, and become much more powerful, so as to be able to force the flow. It will be conceded that this muscle development in heart and bladder results from *effort* to overcome obstruction.

"Displacement of images by prisms and blurred images by means of concave lenses are obstructions which, if not too great, will be overcome by muscular action—the former, by action of the recti muscles; the latter, by action of the ciliary muscles. Many observers have

already acknowledged that rhythmic exercise of the recti muscles, by means of prisms, and of the obliques, by means of cylinders properly placed, not only increases their power, but at the same time dispels the nervous phenomena associated with and dependent on their former weakness. If the ciliary muscles can be developed by rhythmic exercise, then concave lenses, not too strong, used rhythmically, but not too long at a time, may be the means of deferring old sight to five or ten, or even more, years beyond the now common age of its onset—about the age of forty-five years.

"As in developing the recti and obliques, so in the development of the ciliary muscles, the power to overcome obstruction should never be taxed to anything like its fullest capacity. Gentle contraction and relaxation, rhythmic in order, continued from five to ten minutes and repeated once or twice every twenty-four hours, must result in giving tone to the ciliary muscles. The time of life for beginning the exercise, and the strength of concave lenses to use, are matters that must be settled by observation and experience. As a preliminary to the treatment of failing accommodation, all existing focal errors should be corrected, and this correction should be worn behind the exercise lenses at each sitting. A minus .50 D. spherical lens, properly centered, will be the most useful. The patient should be seated from fifteen to

twenty feet from a lighted candle, lamp, or gas jet, and should look at the same through the concave lenses five seconds, and then raise them for a period of five seconds, and so on to the end of the sitting. It is evident that, with the focal correction on when needed, the image of the flame is sharp, satisfying the guiding sensation without ciliary action. The moment the weak concave lenses are lowered the image is blurred, and at once the ciliary muscles are called into action, to again return to a state of rest the moment they are raised. Thus contraction and relaxation are easily induced. In this way the nutrition of the muscle should be improved and its power enhanced or maintained. The age at which to begin the exercise, as a rule, need not be under forty nor over forty-three years, and it should be continued as long as the proper reading distance is preserved.

"The question would naturally arise in the mind of the patient as well as that of the practitioner: 'Can any injury come from the treatment?' The nutrition of the ciliary body is from the blood that circulates in it. Nothing is more reasonable than that gentle, rhythmic, and periodic exercise of the ciliary muscle would improve the nutrition of the ciliary body, just as the nutrition of other muscles is improved by proper exercise. No harm, then, could come to the *muscle* as a result of the proposed gymnastic exercise. May we fear unfa-

vorable change in the lens as a consequence of this exercise of the ciliary muscle? It is generally conceded that the lens gets its nourishment, by the process of osmosis, from the blood circulating in the ciliary body. It must be acknowledged that the better the nutrition of the lens, the more likely will it retain its two very important properties, transparency and elasticity. It cannot be denied that the better the nutrition of the ciliary body, the healthier will be the crystalline lens. We must conclude that, if the exercise would improve the condition of the ciliary body, it would at the same time have a tendency to improve the nutrition of the lens, whereby the latter would be only the more certain to continue both transparent and elastic. Thus not only may old sight be deferred, but also the development of cataract may be prevented."

It is now about eight years since the above was written. During five of these years, beginning at the age of forty-three years, the author faithfully "took his own prescription," hardly a day passing that he did not exercise his ciliary muscles with concave spheres. When the exercise was commenced, there was already beginning presbyopia, interfering somewhat with the finding of foreign bodies in the cornea and with their removal. There was hesitating vision in the more delicate operation on the eye. He commenced the exercise with a mi-

nus .50 sphere and soon experienced increase of ciliary power, as shown in both comfort and convenience experienced in reading and operative work. After a few months a minus 1. sphere was substituted for the weaker lens, and with this the exercise was continued until the age of forty-eight years. Except for the hard work, by artificial light, incident on the writing of this book, he would have continued the exercise longer, possibly until the age of fifty years. Even now, in his forty-ninth year, although he has been wearing a presbyopic lens (a plus 1. D) for the past six months, he can see to read this print easily at fifteen inches through his astigmatic correction only. If the three necessary factors for carrying out this exercise—time, patience, and perseverance—could be kept compounded, much might be accomplished, especially if the exercise were commenced before the age of forty years.

If the exercise treatment is not resorted to, waning ciliary power should be supplemented by convex lenses, as soon as inconveniences arise in near work. There is no reason why plus .50 D spheres might not be first used, and as long as they give comfort. Whenever the ciliary muscles begin to call for more, the presbyopic correction should be increased by steps of .50 D. Finally, when all ciliary power has vanished, artificial aid must be substituted for the lost ciliary power. To give an unneces-

sarily strong presbyopic correction at the beginning should be avoided, for by so doing the nutrition of both the ciliary body and the lens might be interfered with. Presbyopic lenses should always be correctly centered, and they should be set before the eye so that the visual axes would pass through the lenses at right angles.

WEAKNESS OF MÜLLER'S MUSCLE IN THE YOUNG. —Either from the want of proper development of the muscles or because of faulty innervation, the power of accommodation in young people is often found below par. In association with convergence, the printed page may be seen, but prolonged use of the eyes for reading fatigues the weak muscles and brings on headache or other reflex nervous symptoms. If focal errors exist in these cases, they should be corrected as might be indicated by an associated study of the focal errors and intrinsic condition of the lateral recti muscles. In many cases weakness of Müller's muscle is the chief source of trouble; and if comfort is ever to be given such a sufferer, this condition must be treated.

A diagnosis of such a condition may be made easily by means of the concave lenses in the refraction case, but more easily and rapidly by means of two parallel bars containing a series of concave spherical lenses, varying in strength from .50 to 3. D, the difference in strength between any two adjacent lenses being .50 D. These

bars should be so connected above that the distance between them may be regulated to suit the distance between the pupillary centers of the eyes to be tested. The minus .50 should be below; the minus .3 D sphericals, above. Beginning with minus .50 sphericals before the two eyes, the patient all the while looking at the Snellen letters made to be read at twenty feet, each pair of lenses should be passed down in front of the eyes so long as the patient is still able to see $\frac{20}{XX}$. If the muscles of accommodation are weak, ciliary power, unassociated with convergence, will be less than 3. D; in many cases it is not more than 1. D. The standard of ciliary power, when unassociated with convergence, may be placed at 3. D, for the reason that a ciliary muscle that can overcome a minus 3. D, when not converging, can easily accommodate for the reading distance, in association with convergence. Not much help, from a diagnostic standpoint, can come from a test of the relative power of accommodation. The test apparatus just described may be called a "ciliometer." Except for the trouble and inconvenience, the lenses from the trial case could be used for making these tests.

Lucien Howe has devised a more complicated apparatus for testing ciliary power, which he exhibited before the Section of Ophthalmology of the American Medical Association two or three years ago. As the author re-

members the device, he thinks it would be easy to use and fully worthy of trust.

Every protracted illness must weaken ciliary power, which time and tonics will relieve. Such patients should abstain from near work until the general health has been fully restored

TREATMENT.—The treatment of weakness of Müller's muscle is by exercise, after the method set forth in the answer to the question: "Can presbyopia be deferred?" The result of the exercise will depend largely on the faithfulness with which it is carried out. In cases of congenital weakness of the ciliary muscles, strychnia, electricity, and other tonics can accomplish but little. Rhythmic exercise by means of minus .50 to minus 1 D spherical lenses will cure, usually in a few months. The giving of convex lenses to supplement the weak ciliary power should not be considered, for it would be making the patient old while yet young.

BOWMAN'S MUSCLE: ITS NORMAL AND ABNORMAL WORK.—In non-astigmatic eyes, when the position of the lens is ideal from the processes of development, the Bowman muscle can have nothing to do, unless it be to aid in steadying the lens in the act of accommodation by Müller's muscle. Such action, if it occurs, must be of the entire muscle.

If a lens, as the result of the processes of develop-

ment, is not ideally placed in a non-astigmatic eye—especially if its equatorial plane is not parallel with the equator of the eye, and probably if its antero-posterior axis does not coincide with the visual axis—the task of correction of these errors must fall on Bowman's muscle, and the work must be accomplished through the guiding sensation of the retina, most likely in the earlier months of infancy. This regulation of position must be effected by action of a definite portion of the muscle, and it must be kept up unless the suspensory ligament should undergo such change as, in itself, would fix the lens. A failure on the part of the muscle to act would give a permanent lenticular astigmatism. Such work required of Bowman's muscle would be abnormal, but essential.

When there is corneal astigmatism, there is necessity for abnormal action of Bowman's muscle in a localized part. The adjustment of the lens must be such as to increase its refractive power in the part at right angles to the plane of the meridian of greatest curvature of the cornea. This can be effected in one of two ways—first, by a contraction of one single part of Bowman's muscle, so as to rotate the lens on an axis that lies in the plane of the meridian of the cornea that is most curved; second, by the simultaneous and equal contraction of opposite parts of the muscle so as, by pressure on the lens through the tension of corresponding parts of the suspensory

ligaments, to increase the curvature of that part of the lens at right angles to the plane of the most curved corneal meridian. While, in either instance, the corneal astigmatism would be neutralized, in part or wholly, the author inclines to the view that it is effected by the tilting of the lens. This work is abnormal, rarely ever perfectly effective, especially in the higher degrees of astigmatism, and is probably one of the worst kinds of eye-strain. As the patient grows older this astigmatic accommodative power is less able to accomplish its work, and a greater amount of the astigmatism becomes manifest. There is no known drug that will suspend astigmatic accommodation, else at the first examination the whole error could be found, and should be corrected.

There are but two ways to deal with astigmatism: First, correct only the manifest error, increasing the strength of the cylinder from time to time, as the latent error becomes manifest; second, give at once a full correction of the corneal astigmatism, as shown by the ophthalmometer, and thus force the suspension of the accommodative astigmatic power, which would doubtless occur in a short while.

The production of artificial astigmatism, unless indicated by insufficiency of the superior obliques, should always be avoided. To avoid thus calling into abnormal action any part of Bowman's muscle, the correction

of corneal astigmatism should be perfect, both as to strength of cylinder and location of its axis; and when minus spherical lenses are required for the correction of myopia, or plus spherical lenses are given for the correction of hyperopia and presbyopia, they should be so placed that the plane of each lens shall be parallel with the equator of the eye by which it is to be used.

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